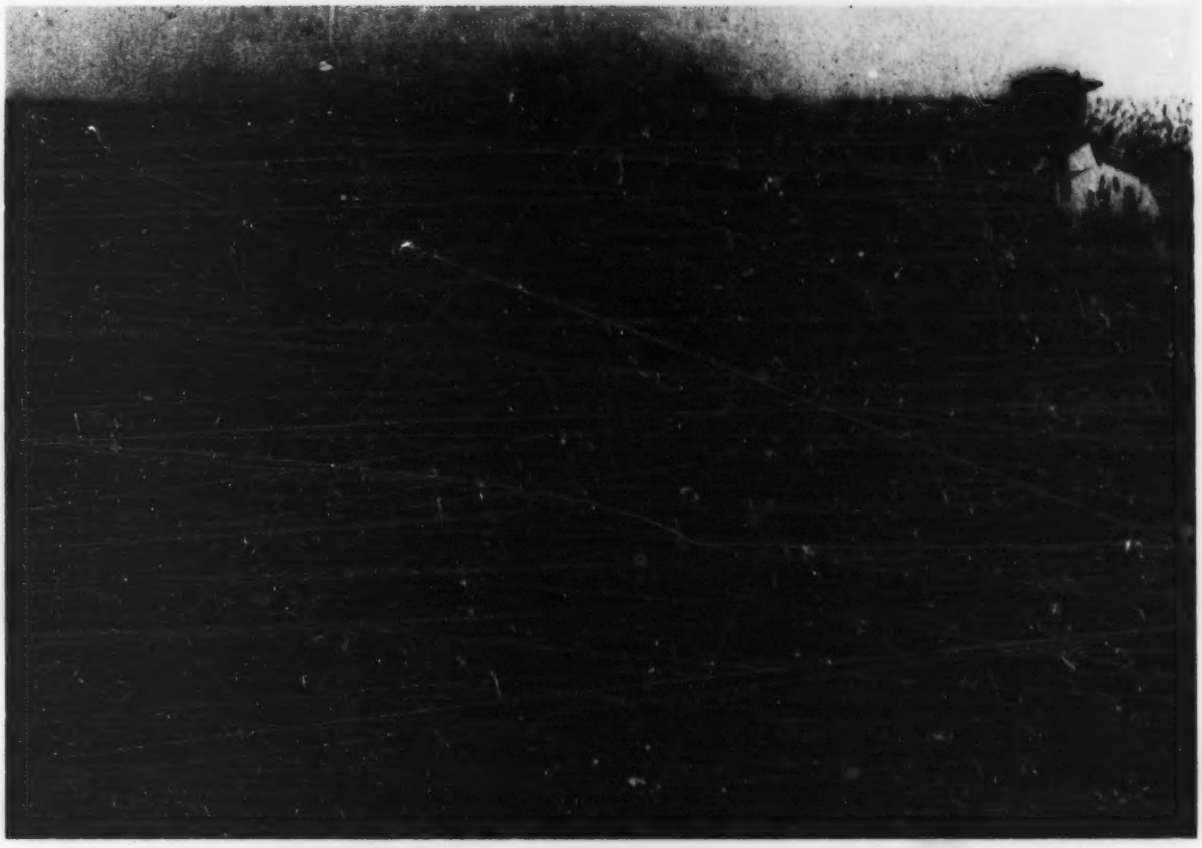
Cropping Systems for a Sustainable Future



long-term studies in Alberta

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Cropping Systems for a Sustainable Future

long-term studies in Alberta

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Cover Photograph: *Good harvest in 1906:*
This field of Alberta wheat was chin-high
and stretched as wide as the horizon.
(Courtesy of Provincial Archives of Alberta,
E. Brown Collection, B.447)

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I. INTRODUCTION

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The years teach much which the days never know.

Ralph Waldo Emerson
American philosopher and poet
Essays, Second Series: Experience
1844

When cultivated agriculture began in Alberta at the turn of the twentieth century, there was scarce information on how to farm the dry and irrigated lands of the Prairies, and the forested lands farther north. Early agriculturalists set up experiments on 'crop rotations,' or planned sequences of crops grown on the same field, to find out which crops grew best in the different climate, soil and vegetation zones of the province.

In the beginning, the experiments were relatively simple. Their purpose was to get a general understanding of the suitability of different crops, where there was little understanding before. They were designed by the Experimental Farms Service of what was then the Dominion Department of Agriculture, and by the Soil Science Department of the University of Alberta.

Now that these experiments have been maintained by researchers for decades, they have become long-term studies of a much greater scope. Data collected every year for many years is invaluable. It overrides fluctuations in weather, and trends in economics and agricultural practices. These long-term studies are precisely the kind of studies that can answer questions about the sustainability of agriculture, on the Canadian Prairies and elsewhere.

Agricultural sustainability depends on the resilience of soils to agricultural practices, the effects of agriculture on the rest of the environment, and the economic viability of the agricultural industry.

It has long been recognized that growing a sequence of crops, rather than the same crop each year, or a 'monoculture,' benefits the fertility of the soil and the production of crops. Nitrogen is used more efficiently. Weeds, insects and diseases can be controlled. These benefits were perceived as less important when technology brought fertilizers and pesticides to agriculture, and interest in crop rotations waned for a time.

Recently there has been renewed interest in the crop rotation experiments. There are several reasons for this. There may be additional benefits to the soil from crop rotations, called 'rotation effects,' which cannot be obtained from fertilizers and pesticides and which require further study. There are concerns that a heavy reliance on fertilizers and pesticides not only increases production costs, but may harm other components of the environment such as water sources and wildlife. And the long-term experiments hold vast amounts of information collected over the years that may help solve agricultural problems in the future, problems not yet envisioned.

Crop rotations are now referred to as cropping 'systems.' When crop rotation experiments were first set up the goal was to find the best sequence, or rotation, of crops. Now, additional factors are included in these studies, such as different applications of fertilizers and manure and different tillage methods, and the studies are managed with a holistic approach.

Researchers, then, manage their rotation experiments as cropping systems. They try to maintain the original design of the experiment, adjusting it only when cropping practices evolve in major ways and become widely adopted on commercial farms. This allows them to analyze the results more rigorously, minimizing the confounding effects of different cropping practices, and to impart reliable information to help sustain the soil resource and the environment.

This approach is not always practical for farmers. Once farmers set production goals, they tend to follow a planned crop sequence that is flexible enough to allow for weather constraints and economic trends. This allows them to remain farmers; their livelihoods and communities sustained.

Many crop rotation experiments were initiated in Alberta at various times during the twentieth century. Some were discontinued after answering the original questions of the experiments. Others remained and became the basis of the crop rotation network in Alberta, known as the Sustainable Cropping Systems Research Study (Table 1).

Agriculture and Agri-Food Canada maintains studies at Lethbridge, Stavely and Beaverlodge. Studies at Breton and Ellerslie are maintained by the University of Alberta. Two new study sites were established in 1991 by Alberta Agriculture, Food and Rural Development, at Bow Island and Three Hills. The new sites fill geographical gaps left by the other studies, so that more Alberta ecosystems are represented. The Stavely site is a native grassland

ecosystem, in contrast to the other sites which are cultivated cropping systems. It is hoped that all seven long-term studies will continue to provide crucial information about the sustainability of agricultural systems in Alberta.

If history is the greatest teacher, the long-term cropping system studies in Alberta contain much information for the future. If this information becomes knowledge, then we will have the power to be the best possible stewards of the land.

What follows are the stories of these studies, and the information they hold.

TABLE 1. The long-term study sites of the Sustainable Cropping Systems Research Study.
The sites are listed from oldest to most recently established.

Site	Date Est.	Location	Maintained By
Lethbridge	1910	1 km E. Lethbridge	Agriculture and Agri-Food Canada
Breton	1930	5 km S.E. Breton	University of Alberta
Stavely	1949	80 km N.W. Lethbridge	Agriculture and Agri-Food Canada
Beaverlodge	1968	0.5 km E. Beaverlodge	Agriculture and Agri-Food Canada
Ellerslie	1980	10 km S. Edmonton	University of Alberta
Bow Island	1991	16 km S.W. Bow Island	Alberta Agriculture, Food and Rural Development
Three Hills	1991	3 km S.E. Three Hills	Alberta Agriculture, Food and Rural Development

II. IN THE BEGINNING

Dry farming, undoubtedly, was started in southern Alberta by ranchers growing a few acres of oats for their horses.

A.E. Palmer, Superintendent
Lethbridge Experimental Station
1945-53

1. Alberta at the Turn of the Twentieth Century

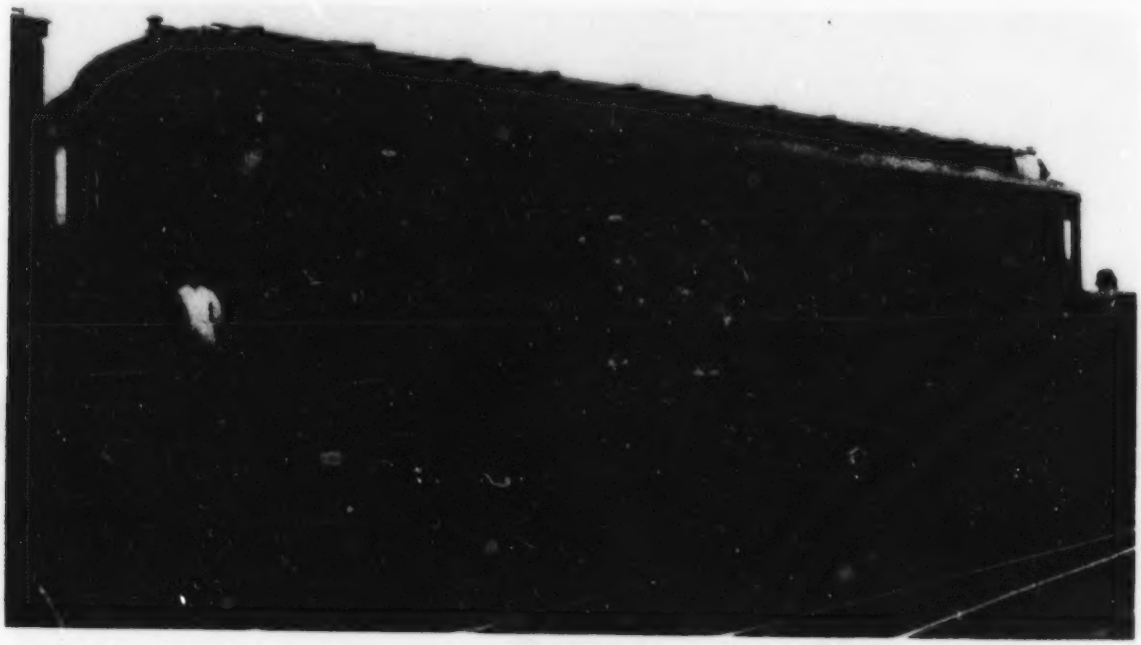
At the turn of the century, the land that is now Alberta was seen as a mecca; a sunny land filled with opportunities. Since the completion of the railroad across the Prairies in 1885, the Canadian Pacific Railway Company encouraged settlers to ride the rails out west and purchase land granted to the company in return for this mammoth task. In the decade after the railroad was built, Alberta's population grew from about 7,000 to 30,000, but the real boom was yet to come in the early twentieth century.

An earlier explorer to the area would have predicted no such boom. In 1857, Captain John Palliser prepared the Palliser Report during an expedition to determine if the Canadian Prairies could be settled. In his report, Captain Palliser said a triangle of land in the southwestern Prairies could not be settled, because of low and sporadic rainfall and a lack of water and trees. The Palliser's Triangle roughly matched the Brown and Dark Brown soil zones within Alberta and Saskatchewan. But a more thorough examination of the area by Professor John Macoun in the 1870s led to a more favorable report, and to increased settlement.

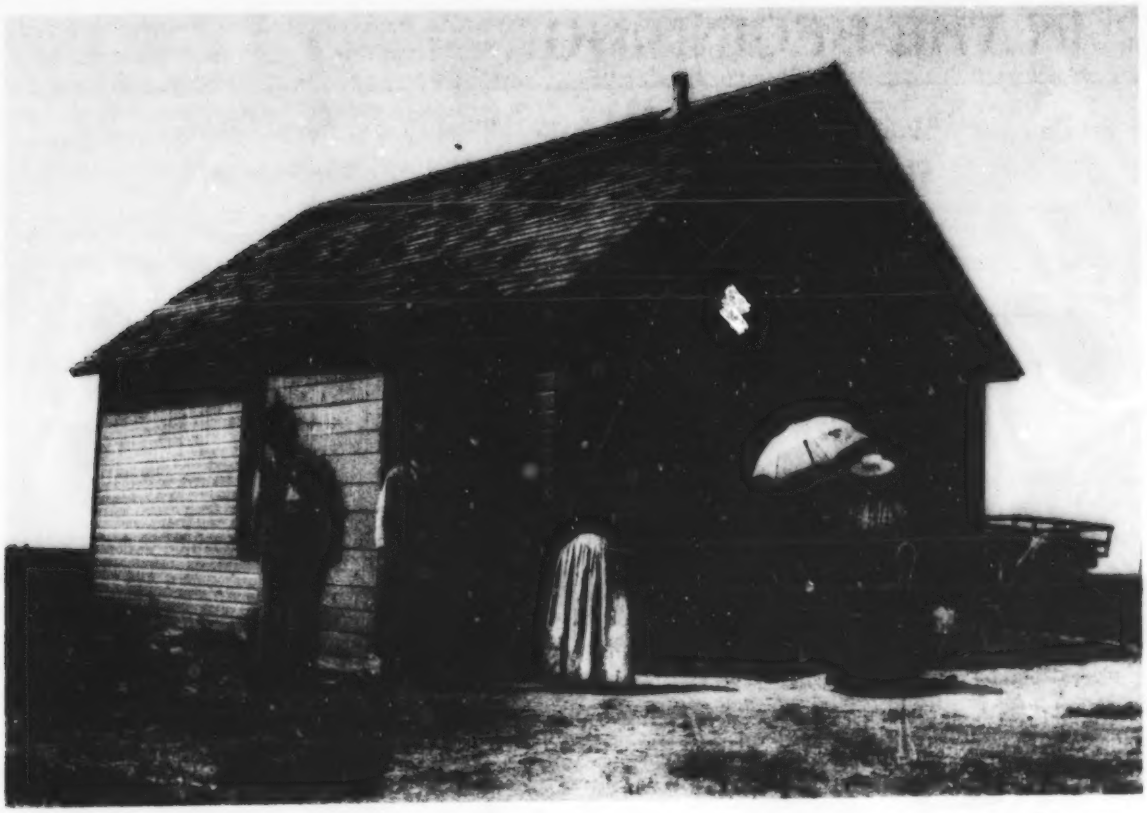
Farming on the Prairies began in a serious way in the 1870s, and was based on techniques used in Ontario. But even by the late 1890s, agriculture was still in its infancy in Alberta. Instead, ranching had a much stronger appeal. It was a time when "grass and water were as free as the sunshine and ridin' and ropin' took everyone's fancy," as a Lethbridge editor wrote.

There were some crops grown in southern Alberta at this time, but mainly to feed horses and cattle. Oats were grown and the grain was sold to the North-West Mounted Police, to feed their horses. Some ranchers cut their crops green to feed as forage to livestock.

Small acreages of winter wheat were grown suc-



Immigrants arriving at Lethbridge from Dayton, Ohio, in a Pullman (tourist car) in 1908.



Settlers in front of a newly constructed frame house, circa 1905.

cessfully in southern Alberta in the 1880s. In one early account, Pincher Creek farmer Francis Willock described his own experimentations with growing winter wheat:

> *"In the spring of 1883, I arrived in this country, bringing along with other things a few grains of wheat, which I believe to have been Early Red Clawson. I sowed it in the garden the same fall. Next spring it grew rapidly until ripened. While ripening, a gopher destroyed most of the crop, leaving but ten heads. These heads I threshed out in my hands, sowing the proceeds in the fall of '84. In the summer of '85 there was enough to sow about two rods* (10 metres). *The next year I sowed seven-eighths of an acre."*
>
> (from 1961 paper by A.E. Palmer entitled *History of Dry Farming on the Canadian Prairies)*

Around 1900, the emphasis in southern Alberta began to shift from ranching to irrigated farming. The North Western Coal and Navigation Company played a role in this.

Coal had been discovered near Lethbridge in about 1870, and in the 1880s the coal company built narrow-gauge railways to transport coal from Lethbridge to Medicine Hat and Great Falls, Montana. In return for building these railways, the company received land grants from the Canadian government.

In the 1890s, the company, renamed the Canadian North-West Irrigation Company, built canals so that water could be brought from sources in the Rocky Mountains and the semiarid land could be sold to settlers for agricultural use. The first main canal, from the St. Mary's River to Lethbridge, was completed in 1900. Irrigation was a new concept in southern Alberta, and it was seen as a way to guarantee large yields and grow many diverse crops.

Alberta became a province in 1905, its boundaries formed out of what was then part of the Northwest Territories. Settlement in Alberta was strongly promoted by the government, and many farmers began to settle on dryland farms in the south in 1905 and 1906. Sod could now be broken using the newly introduced steam tractor, an innovation which helped encourage farming.

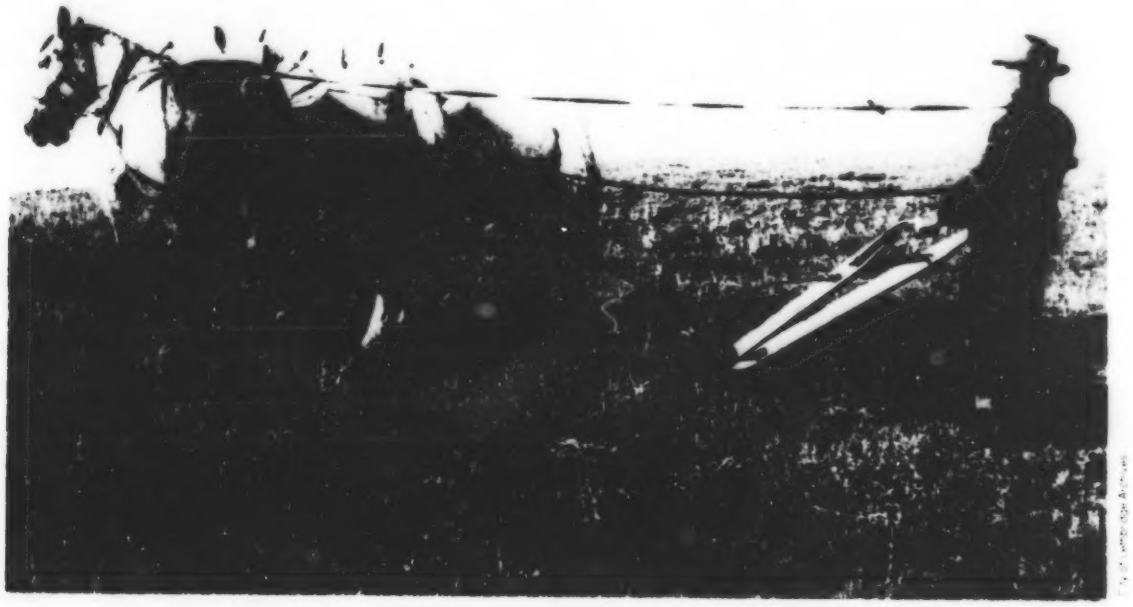
An aberration in the weather also encouraged farming. During the winter of 1906-07, the climate was unusually cold. The warm Chinook winds nor-

mally experienced in southern Alberta did not come that winter, so the grass remained covered. The snow was deeper and stayed longer, and thousands of cattle starved to death. It was several years before the ranges could be restocked, and during this time many homesteaders came to southern Alberta to farm, filling the void left by ranching. Dryland farming, along with irrigated farming, was coming into its own.

Settlement was initially concentrated around the railroad, which was built across southern Alberta first. But after the railway to Edmonton was completed in 1905, more settlers ventured north into the forested areas, particularly from 1910 to 1920 when lumber companies were clearing forests. What the settlers found was land that supported good stands of trees, leading them to believe the region was highly fertile. Some who had homesteaded on the dry prairie soils of southern Alberta moved farther north because they believed the moister climate offered fewer limits to agriculture.

A 1912 Railway Company brochure enticing prospective settlers described Alberta as "one of the most healthful countries in the world" because of its clear, dry atmosphere, sunshine and fresh breezes. According to the brochure, the growth of native grasses was marvellous, the soil was fertile, and the opportunities to become independently wealthy were abundant.

Amid the promotions of the railway brochure, a small warning had appeared, that "those living in such a country must make homes before they can make money." Many showed they were up to that challenge. In 1906 the population of the new province was 185,000 and by 1914 it had grown to 470,000. Along with making their homes, the settlers purchased land, and broke the native sod so that a living could be made.



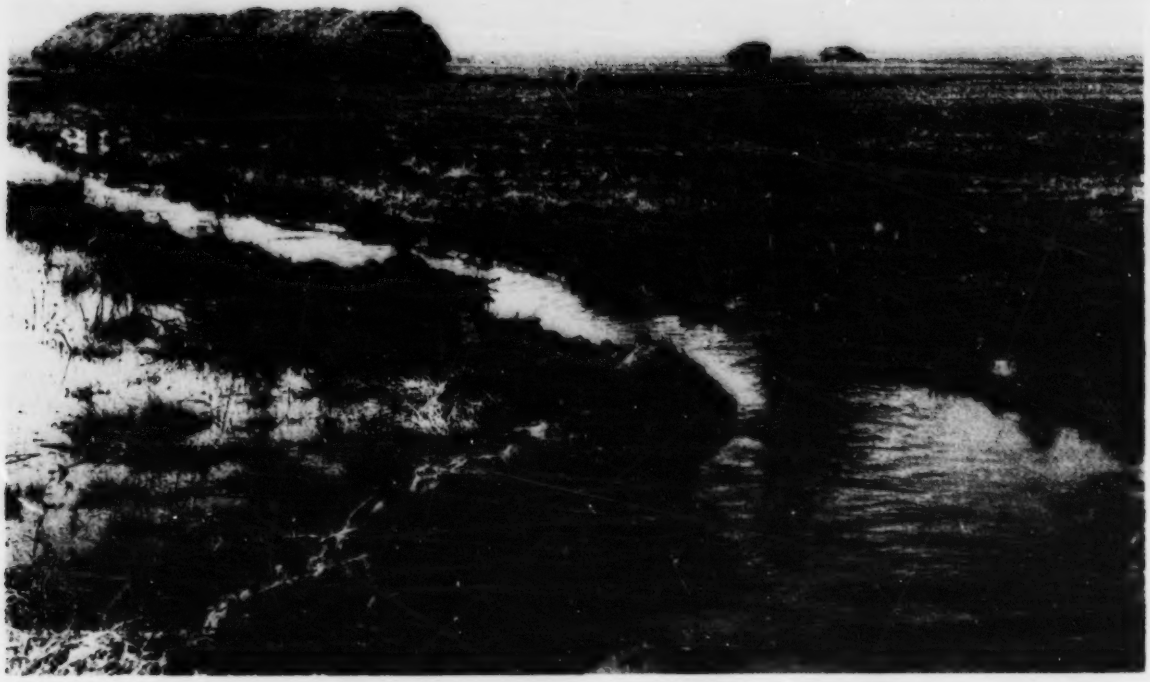
Using a single blade walking plow to break virgin prairie, circa 1900.

2. The Challenges of Agriculture

The breaking of the native prairie sod around the beginning of the twentieth century created a need. The need was for information on how to grow a variety of agricultural crops on land that had sustained only native plants, and predominantly grasses, for thousands of years. Although some farmers had come to the Prairies with a previous knowledge of agriculture, none could know the unique characteristics shaping this land, nor the problems and challenges they would face farming it.

In Canada, the government responded by setting up substations of the Central Experimental Farm in Ottawa. By the end of the 1890s there were two substations on the Prairies: one at Brandon to serve the Manitoba farming front and the other at Indian Head to serve the Northwest Territories, of which Alberta was still a part.

By the time Alberta became a province in 1905, the agriculture in its southwestern portion was particularly diverse. The moderating effect of the warm Chinook winds, combined with irrigation waters,



City of Lethbridge Archives

Flood irrigating alfalfa at the Lethbridge Research Centre, circa 1920.

City of Lethbridge Archives

Interior of the Lethbridge Board of Trade, 1913. D.J. Hay, secretary at the Board, is behind the counter. It is believed the photographs and display materials, which pertain to the Lethbridge area, were used for the 7th International Dry Farming Congress held in Lethbridge the previous year. A plaque serves as a memento of an earlier congress held in Billings, Montana.

allowed the growth of vegetable as well as cereal crops. But more knowledge was needed to solve the unique problems associated with a diverse, irrigated agriculture than was provided by the prairie substations. The only available information on growing similar agricultural crops came from the humid, forested province of Ontario, and it did not apply to the drier prairie ecosystem.

The Canadian North-West Irrigation Company, which had made irrigation possible, tried to provide advice to irrigation farmers in the Lethbridge area. In 1901, company manager Charles Magrath invited Professor William Fairfield of the University of Wyoming to operate a model farm at Lethbridge, and to demonstrate to farmers the most advanced methods used in irrigated farming.

The farmers who had settled on dryland farms since about 1905 also needed help solving problems — a different set of problems than those encountered on irrigated farms. In 1906, the fifth substation of the Central Experimental Farm opened at Lethbridge, and Professor Fairfield became its superintendent. The Dominion Experimental Station at Lethbridge, now known as the Lethbridge Research Centre, was to become the largest regional substation of Agriculture and Agri-Food Canada.

The new experimental station consisted of 160 hectares (400 acres) of native prairie, of which 40 hectares (100 acres) were set aside for irrigation experiments. Most of the remaining land would be used for experiments on dryland farming. Professor Fairfield maintained that there were actually two experimental farms — one dry and the other irrigated. Each had its own set of problems. The two were never compared, and the results were published separately in annual reports.

Dryland agriculture was still a relatively new technique in 1908, when it was showcased to the world at the International Dry Farming Congress in Cheyenne, Wyoming. But by 1910, dryland farming was becoming established in the Lethbridge area, and in 1912 the Dry Farming Congress was held in Lethbridge. These congresses served to further educate people about dryland agriculture, and to identify the challenges in southern Alberta.

It was apparent that the semi-arid climate of the southern Alberta prairie was dry enough to impose serious limitations to crop growth, particularly if crops were grown continuously (Figure 1). The amount of soil moisture carried over from a previous year's crop was not necessarily enough to sustain the next year's crop through the growing season, especially during a year of below average precipitation.

There were different challenges in the forested regions of central and northern Alberta. Instead of the limited rainfall of the south, there was limited heat during the growing season and there were fewer days without frost (Figure 2). Also the forest soils, known as Gray Luvisolic or Gray soils, were not well suited to cultivated agriculture. The forest soils naturally contained lower amounts of organic matter and nutrients than the grassland soils farther south; a moist climate had washed these substances away. The soils were slightly acidic because soil particles that neutralize acid, such as clays and carbonates, had also been washed away. And, when cultivated, the Gray soils were difficult to manage because hard crusts formed on the soil surface after rainstorms.

In some respects then, the first impressions of those settling in central and northern Alberta had been wrong. Although the forest soils supported a lush growth of trees, it was the grassland soils farther south — the Brown, Dark Brown and Black Chernozemic soils (hereafter referred to as Brown, Dark Brown and Black soils) — which, despite their dryness, were more fertile than the Gray soils, and more suited to the growing of herbaceous plants such as agricultural crops.

3. Meeting the Challenges

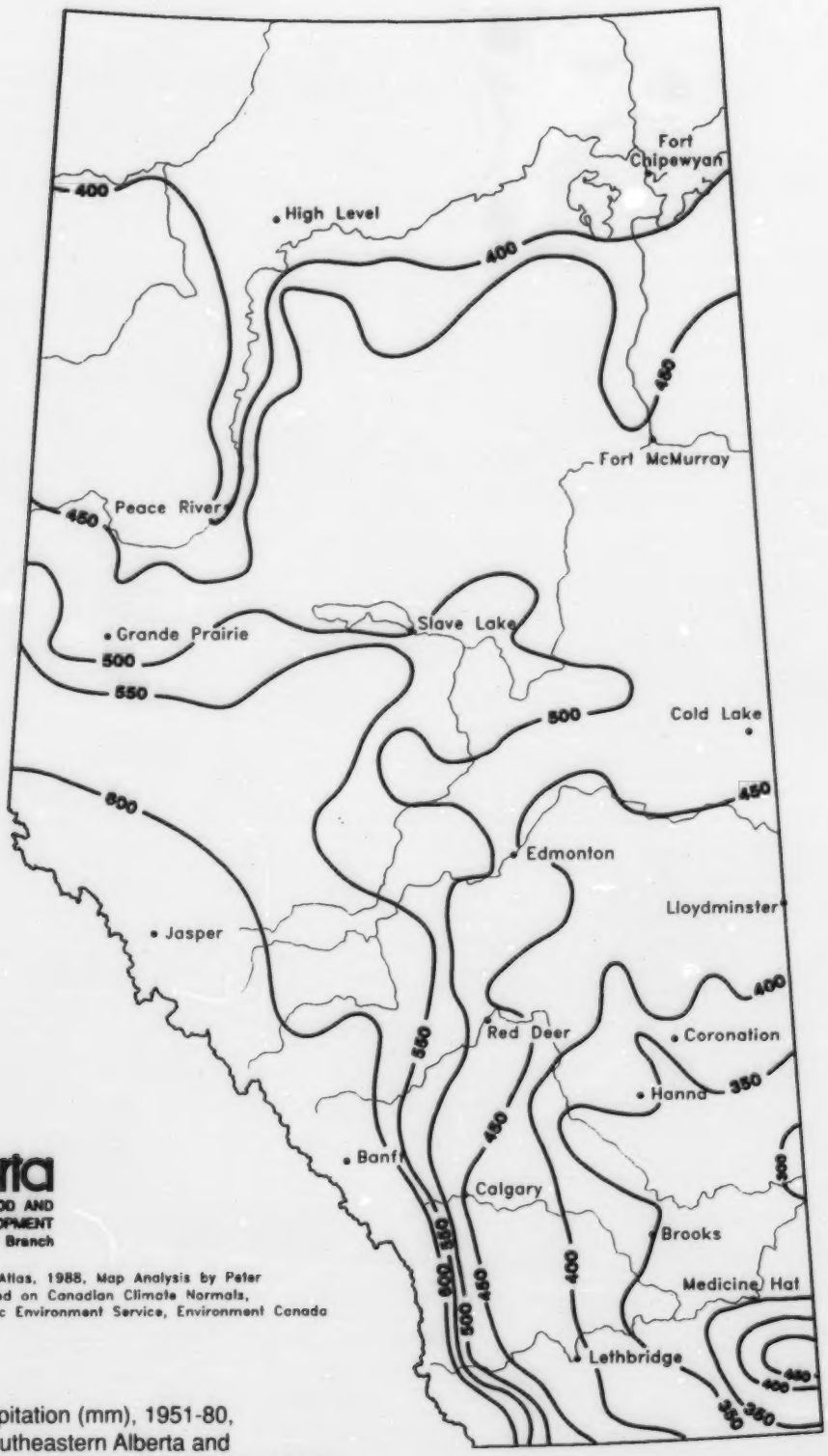
The dry, erodible prairie soils

It was in Lethbridge that the first cropping system studies in Alberta were established in 1910. This was the beginning of two long-term crop rotation studies, Rotation ABC and Rotation U, which are still maintained today.

Rotation ABC was established on a dryland site at the Lethbridge Research Centre to test the practice of summerfallowing as a way to conserve soil moisture in the semi-arid region of southern Alberta. The experiment showed it was beneficial for farmers in this region to keep one-third of the land in fallow. However, summerfallowing was not used extensively in southern Alberta until the 1920s.

Summerfallowing was discovered on the Prairies almost by accident, at the Indian Head Experimental Farm in 1886. In the spring of 1885, some farmers in the area left to transport army supplies for the Riel Rebellion, before seeding their fields. When they returned it was too late to seed, so the land was left fallow and seeded the next spring. The year of 1886 was dry, but it was noted that crops on summerfallowed land grew much better than other crops.

The adoption of summerfallowing on the Prairies contributed to the success of dryland farming by storing moisture during fallow years. But along with it came a mistaken perception about cultivation that contributed to another problem: soil erosion. Since weed-free fallow fields stored the most moisture and produced the best yields the following year, it was assumed that a bare soil or 'black fallow' was most desirable, and that the cultivation used to achieve such a fallow also benefited the soil. In fact, tilling a



Alberta
AGRICULTURE, FOOD AND RURAL DEVELOPMENT
Conservation and Development Branch

Source: Alberta Agroclimatic Atlas, 1988, Map Analysis by Peter Dzikowski, P.Ag. Based on Canadian Climate Normals, 1951–80, Atmospheric Environment Service, Environment Canada

Figure 1. Annual Total Precipitation (mm), 1951-80, showing lower amounts in southeastern Alberta and higher amounts in the north, and in the west (mountain effect).

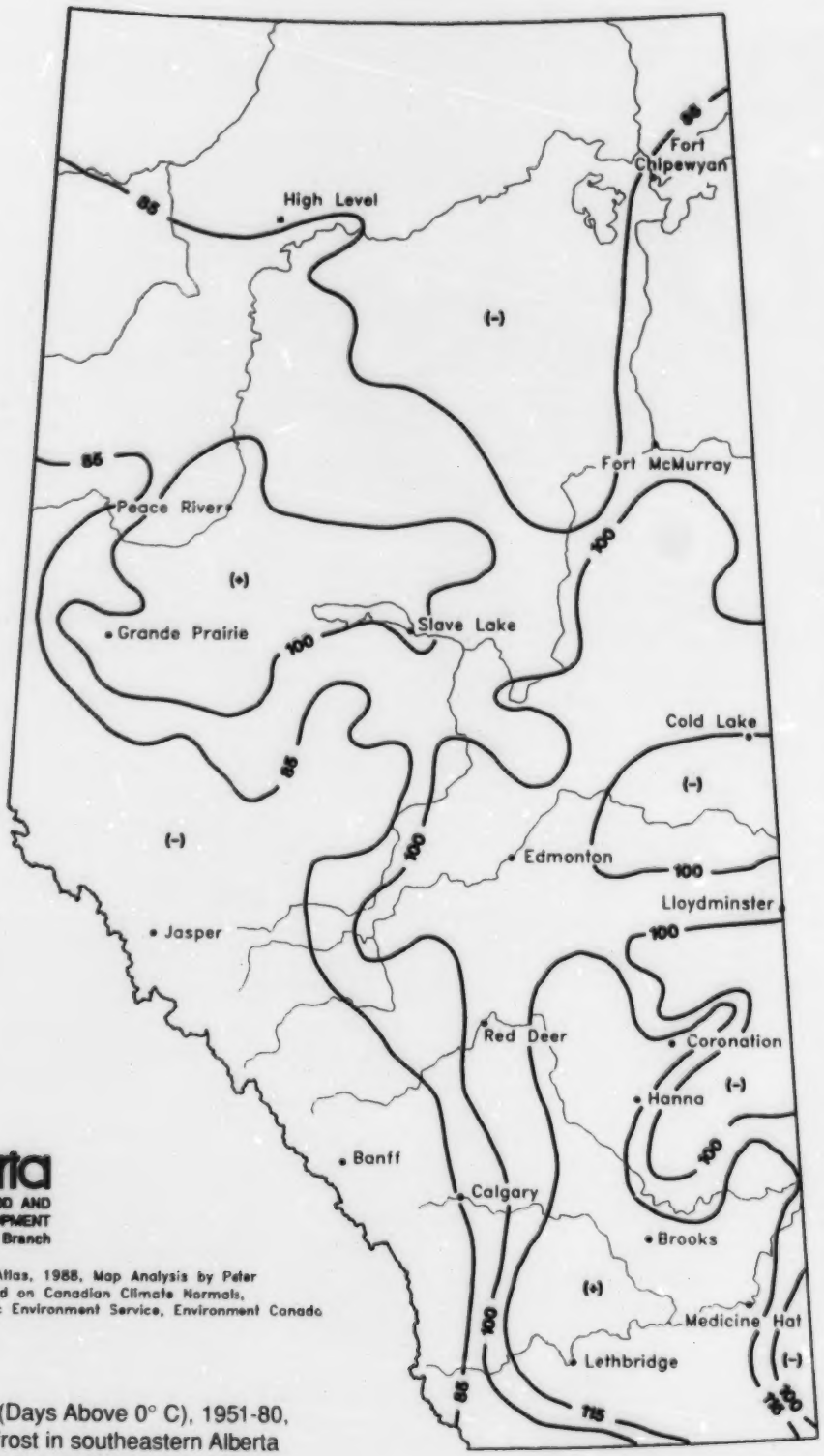


Figure 2. Frost-free Period (Days Above 0° C), 1951-80, showing more days without frost in southeastern Alberta and fewer in the north, and in the west (mountain effect).

field buries crop residues below the surface, and leaves the unprotected soil susceptible to both wind and water erosion. Excessive tillage contributed to severe soil erosion and degradation, particularly during the 'dustbowl' conditions of the 1930s.

With the introduction of herbicides in the late 1940s, weeds could be controlled using less intensive tillage. Advances in herbicides and farm machinery during the 1960s and 1970s led to the development of minimum and zero tillage agricultural practices. In agricultural systems where these practices are used, weeds are controlled partially or entirely by herbicides rather than by tilling the soil. And rather than bare soil, stubble and other residues from the previous crop remain on the field during the fallow year, reducing soil erosion.

Another way of solving the soil moisture problem in southern Alberta was by irrigating. Early experiments on irrigated areas of the Lethbridge Research Centre showed that hay, especially alfalfa hay, was the crop most likely to make an irrigated farm profitable, because of the many horses and mules used to build railways and irrigation systems at the time.

So in 1911, irrigated Rotation U was established. Originally a ten-year rotation, it consisted mostly of alfalfa hay (six years), followed by three years of cereals and one year of potatoes (later replaced with sugar beets). Although modified, Rotation U is still maintained today, and is believed to be the oldest continuous irrigated rotation in North America.

Soil conservation is now of utmost importance on the Prairies. Technology has reduced the negative impacts of summerfallowing. Techniques like strip farming, where strips of fallow alternate with strips of crop, protect the fallow strips from erosion. Tillage implements like the Noble Blade, a wide blade cultivator invented by Lethbridge-area farmer Charles Noble, kill weeds by cutting their roots below the surface, but leave the crop stubble standing to protect the soil.

Many farmers in the south conserve the residues of harvested crops on the soil surface, especially since a dry climate produces a shortage of these residues. Conserving crop residues reduces not only soil erosion but also moisture loss. Recently, direct seeding has received attention as a method of placing the seed in the ground with minimal disturbance to the soil and maximal retention of surface residues. Since 1910, other cropping system studies have been established at Lethbridge to study a greater variety of crops and fertilizer treatments, and different methods of summerfallowing.

The cold, low-nutrient forest soils

In 1930, amid warnings from soil survey reports about the effects of cultivation on forested soils in central and northern Alberta, soil scientists Drs. Wyatt and Newton of the University of Alberta established the Breton Classical Plots. In a 1930 bulletin, Drs. Wyatt, Newton and Mather wrote:

> *"A system of farming suitable for the wooded soil belt, generally, is as yet to be established."*

The wooded soils, now called Gray Luvisolic or Gray soils, are different from the grassland (Chernozemic) soils. They have a surface layer of decomposing leaves, or 'leaf litter.' This layer of organic matter, called the *L-F-H* (formerly *Ao* horizon), lies upon mineral soil. Below the *L-F-H* is the first layer of mineral soil, the *Ae* horizon. Much of the organic matter and clay have been washed from the *Ae* horizon. Below the *Ae* is the *Bt* horizon, where the clay has accumulated.

When Gray soils are cultivated, the *L-F-H* layer, the *Ae* horizon and the top portion of the *Bt* horizon are mixed together to form a new, plowed horizon called the *Ap*. Organic material from the *L-F-H* layer decomposes rapidly, and the characteristics of the *Ae* horizon dominate in the new *Ap*. Consequently, the *Ap* horizon is low in organic matter and nutrients, and ashy-gray in color. It is prone to surface crusting after rainfall, which causes management problems such as water runoff and poor seedling emergence.

The Breton Classical Plots were set up to find solutions to the fertility and management problems encountered in farming the Gray soils. The University of Alberta soil scientists compared two cropping systems: one a monoculture that included only wheat, and the other a rotation that included nitrogen-fixing legumes as hay crops, as well as wheat and other cereal crops. They studied the benefits of including legumes and other crops in a rotation, and of using soil amendments such as fertilizers, manure and lime.

In 1980, there was renewed interest in the crop rotations. Fertilizer treatments were revised for the Classical Plots. Higher rates of nitrogen, phosphorus and potassium fertilizers were applied to reflect modern fertilizer recommendations and to pinpoint the effects of each fertilizer. New cropping system studies were also established at the Breton site. Some of these studies were duplicated at a site near Edmonton, the Ellerslie site, on Black soils. This allowed the cropping systems to be compared on Gray and Black soils. To try to improve the fertility and physical structure of the soils, grasses as well as legumes were introduced into crop rotations, straw was returned to the soil after harvest, and zero tillage practices were used.

The 'Peace Country'

Farther north and to the west of Edmonton is the Peace Country, named after the Peace River which flows through it. In 1917, an Experimental Farm was

established by Agriculture Canada at Beaverlodge to study cropping systems and soils in the Peace River region. Now known as the Beaverlodge Research Station, it is the most northerly of the research stations in Canada.

From 1960 to the mid 1980s there was increased settlement in the Peace Country, and more land was cultivated. It was during this time of expansion that crop rotations were established at Beaverlodge, in 1968. The soils are Gray, as at Breton, but the climate is slightly warmer and drier than at Breton, despite Beaverlodge being farther north. This provided the opportunity to compare two similar Alberta soils under different climates. Because of their similarity to Breton soils, the soils at Beaverlodge showed similar problems with structure and fertility, and these problems have been studied at the Beaverlodge Research Station using grasses, legumes and oilseeds in rotation with cereals.

Another agricultural challenge in the Beaverlodge region is managing crop residues during the growing season. In the spring, excess crop residues produced by the relatively moist, northern climate keep the soil cool, especially when zero tillage practices are used. This can hamper seed germination or seedling emergence. Researchers at Beaverlodge have found that if crop residues are pushed to the side in rows and the seeds are planted in the cleared area, the seeds receive more heat from the sun and have a better chance of germinating. Later in the growing season, when lack of moisture can limit crop growth, the crop can draw on water reserves conserved beneath the rows of residues.

Various tillage implements used to manage crop residues have also been studied. The goal is to distribute residues evenly, without disturbing the soil too much. New studies set up in 1991 were designed to test zero tillage and deep tillage practices, which were of interest to farmers in the area. Deep tillage mixes clay from lower soil horizons to upper ones where the nutrients can be used by the crop. Summerfallowing has been largely abandoned because it breaks down the structure of Gray soils, and moisture conservation is less imperative in the Peace Country.

Filling the geographical gaps

More recently, two long-term cropping system studies were established by Alberta Agriculture, Food and Rural Development. The Bow Island and Three Hills sites were established in 1991, to fill information gaps for two distinct geographical areas of the province: (1) the Brown soils in the south and (2) the non-Chinook region of the Dark Brown soils (sometimes referred to as Thin Black soils), between Lethbridge and Edmonton. These studies will help complete the knowledge base on the sustainability of agricultural systems in most of the geographical areas of Alberta that are suited to agriculture.

III. WHAT THE STUDIES SHOW

Regardless of cropping system, periodic rotation of crops is recommended for the control of certain weeds, diseases and insects.

Research Branch, Agriculture Canada
Crop Rotation Studies on the Canadian Prairies
1990

There are many benefits from using crop rotations, or cropping systems, in agricultural production. When a variety of crops are grown — cereals, oilseeds, legumes, grasses — the various kinds of organic matter returned to the soil help improve its fertility, providing more nutrients to plants. Other effects, on the 'quality' of the soil, are subtle and less understood. Referred to as 'rotation effects,' they cannot be explained by the principles of nutrient cycling but are related to how the different crops in a rotation affect the soil in different ways. Rotation effects occur from interactions among plants, soils and microorganisms.

Rotation effects also occur from differences in water use by crops, or by the lack of crops. Oilseed crops like flax and canola generally use less water than cereal crops. Forages like alfalfa use up moisture stored in the soil, and summerfallowing contributes to it. Water use is most efficient and soil quality is most benefited when crops with different root systems and moisture requirements are used in a rotation.

As stated in the quote at the beginning of this chapter, one of the most important rotation effects is the control of pests, including weeds, diseases and insects. When the same crop is grown year after year, conditions develop that create an ideal environment for certain pests. With rotations, these conditions are disrupted and pest infestations are discouraged. Also, chemicals released by certain crops in a rotation can affect subsequent crops. These chemical interactions among crops, known as 'allelopathy,' can have herbicidal effects. While it is known that rotations can control some pests, it is still one of the least understood effects and needs further study.

Another suspected rotation effect is a greater resistance to soil erosion. Soil aggregates can be stabilized, so they are less likely to break down when exposed to rain, wind and freeze-thaw cycles. Soil tilth, or physical structure, can also be improved. And crop performance can be enhanced, again because of allelopathy.

There are also benefits to the environment. Improved crop performance and pest control means fewer applications of fertilizers and pesticides, which could otherwise contaminate water sources and wildlife. And because the soil resists erosion, the fertilizers and pesticides that are applied are less likely to be moved to other areas by water or wind. Habitat for some wildlife species is improved as the landscape cover is diversified. This is especially true for species that depend on agricultural land for habitat.

Their populations are often better sustained on agricultural land if there are diverse rotations rather than monocultures, especially if those rotations include perennial forages.

In addition to benefiting soil and the environment, cropping systems provide economic stability. Diversifying by growing different crops takes advantage of higher prices for certain crops, and builds a healthier soil for future crops. Crop pests do not build up to numbers where crops can be demolished, because food sources and soil conditions are constantly changing. And the timing of field work is more evenly distributed over the season. For example, fall-planted cereal crops like winter wheat are harvested in mid-July, legumes are cut for silage in mid-August, and cereals planted in the spring are harvested in early September.

A difficulty of studying rotation effects is that long-term trends may not become apparent for many years. They may be clouded by short-term fluctuations in weather and soil productivity — or by current management practices, plant cultivars and scientific theories. However, all of the long-term cropping system studies mentioned here include some rotations that are similar, or standardized. The results from these standardized rotations can help emphasize long-term trends.

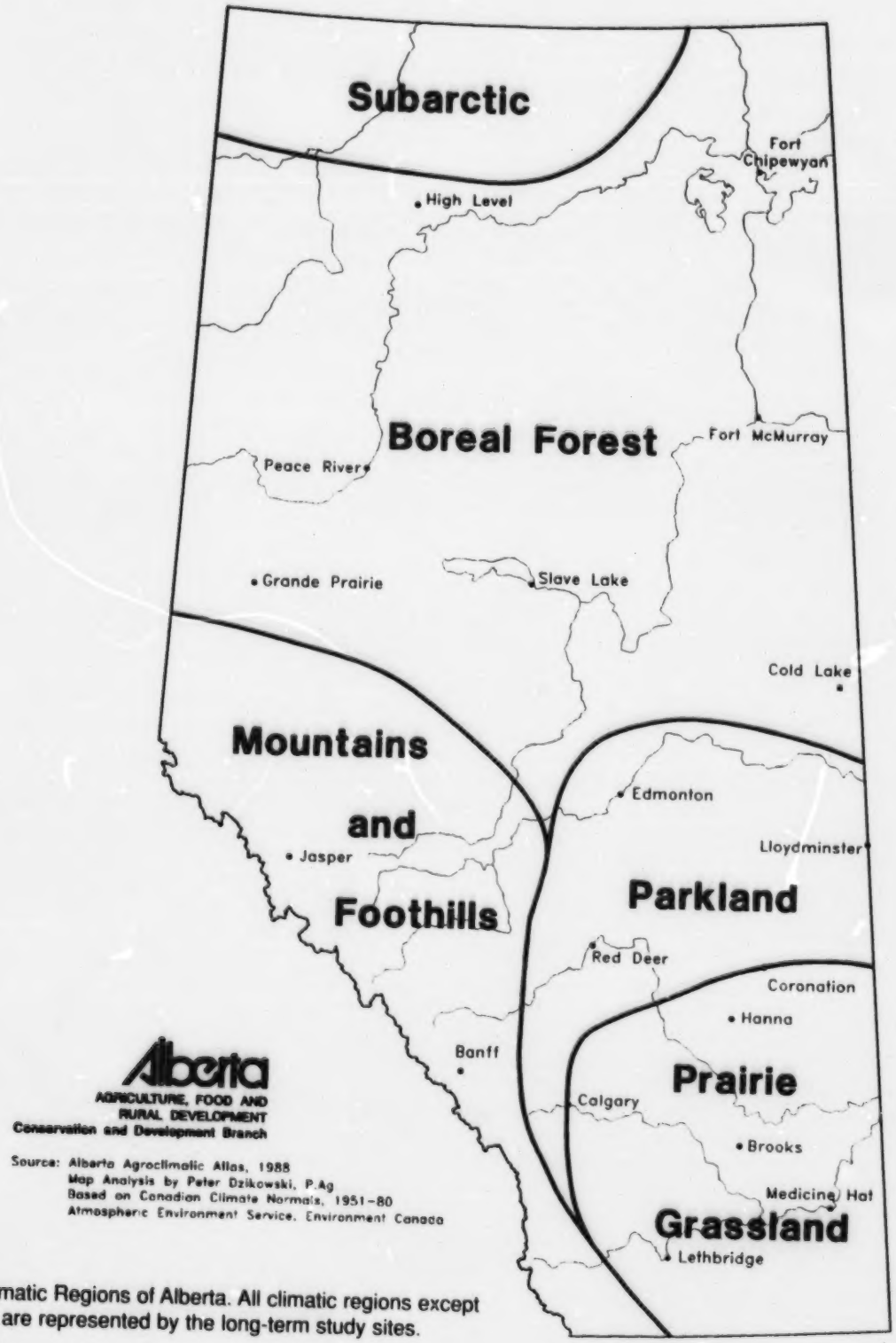


Figure 3. Climatic Regions of Alberta. All climatic regions except the Subarctic are represented by the long-term study sites. (See Table 2)

TABLE 2. The long-term study sites: Climates. The sites are listed from southeast to northwest, showing the general trends of increased precipitation, shorter growing seasons (fewer days without frost) and cooler overall temperatures. Correspondingly, agricultural production is limited by insufficient moisture in the south and by insufficient heat farther north. All data are long-term averages (at least 30 years), except Stavely (20 years). Where data were unavailable at the actual site, values for the nearest meteorological stations are shown. (Compiled from various sources)

Site	Climatic Region	Annual Precip. (mm)	Frost-Free Days	Temperature (° C) January Min.	January Max.	July Min.	July Max.	Limits to Agriculture*
Bow Island	Prairie Grassland	358	110-140	-14.8	-3.8	11.1	26.5	Moderate to slight moisture limitation
Lethbridge	Prairie Grassland	387	100-120	-14.6	-2.8	10.5	25.6	Slight moisture limitation
Stavely	Mountains and Foothills	594	90	-15.0	-2.3	9.9	24.9	Severe to very severe heat limitation
Three Hills	Parkland	408	90-110	-17.8	-7.7	9.9	24.4	Slight moisture and heat limitations
Ellerslie	Parkland	455	90-110	-20.7	-10.5	9.7	22.3	Slight to moderate heat limitation
Breton	Boreal Forest	547	80	-19.5	-8.6	8.8	21.2	Severe to moderate heat limitation
Beaverlodge	Boreal Forest	468	105	-18.1	-9.0	8.9	21.6	Moderate heat limitation

* Modified from Pettapiece, 1989. *Agroecological Resource Areas of Alberta.* Agriculture Canada.

TABLE 3. The long-term study sites: Vegetation and Soils. The sites are listed from southeast to northwest, showing how changes in native vegetation have affected soils. In the south, Chernozemic soils have developed under grassland vegetation whereas farther north, Luvisols have developed under forests. Within the Chernozemic soils, organic matter content increases from south to north, apparent in the progressively darker color of the soils. Climate also shapes soils; there are more trees farther north because of a moister climate (see Table 2).
(Modified from Strong and Leggat, 1981. *Ecoregions of Alberta.* Alberta Energy and Natural Resources)

Site	Ecoregion	Key Plant Species	Soil
Bow Island	Arid Grasslands (Shortgrass Prairie)	spear and grama grasses	Brown (Brown Chernozemic)
Lethbridge	Arid Grasslands (Mixed Grass Prairie)	spear, wheat and grama grasses	Dark Brown (Dark Brown Chernozemic)
Stavely	Semiarid Grasslands (Fescue Prairie)	fescue and oatgrass	Thin Black (Black Chernozemic)
Three Hills	Semiarid Grasslands (Fescue Prairie)	grasses, shrubs and aspen bluffs	Thin Black (Black Chernozemic)
Ellerslie	Transitional Grassland (Aspen Parkland)	fescue, shrubs and aspen bluffs	Thick Black (Black Chernozemic)
Breton	low Boreal (deciduous + mixed wood)	aspen and some White Spruce	Gray (Gray Luvisol)
Beaverlodge	low Boreal (deciduous + mixed wood)	aspen and some White Spruce	Gray and Dark Gray (Gray and Dark Gray Luvisols)

Standardization can also pinpoint differences due to geography. The study sites are all located in different geographical areas of Alberta, with different climates, native vegetation and soils (Figures 3, 4 and 5; Tables 2 and 3). But because some rotations are similar, the studies form an integrated research network across the province that allows researchers to compare their results.

One standardized cropping system included in all the studies tests summerfallowing, using either *Fallow-Wheat* or *Fallow-Wheat-Wheat*. Other standardized systems test continuous cropping, using (1) cereals such as wheat or barley, (2) more than one type of crop rather than a monoculture, and (3) forages — any combination of perennial grasses or legumes alone or mixed. Another standardized system tests green manuring, or plowing annual legumes into the soil in the middle of the growing season.

Fertilizer treatments are often standardized, too. Usually a manure treatment is included, nitrogen and phosphorus are compared alone and together, and there are control treatments where neither fertilizer nor manure is added.

Standardization of the cropping systems allows researchers to work together, and to observe rotation effects under different climate and soil conditions. For example, continuous cropping is most successful in areas of adequate moisture. There is no need to summerfallow in these areas, and much higher yields are obtained by continuous cropping. But in the driest soils of southern Alberta, continuous cropping may not be feasible, and it may be an advantage to summerfallow. Future agricultural recommendations will depend on the relative success of similar cropping systems in different geographical areas.

1. The Original Studies

LETHBRIDGE AND STAVELY
Southwestern Alberta
(Agriculture and Agri-Food Canada)

Oldest cropping system studies in Alberta

The oldest crop rotations in Alberta were established in 1910 at what is now the Lethbridge Research Centre, on the eastern outskirts of the city of Lethbridge. Some of these plots are still maintained 85 years later. Both dryland and irrigated cropping systems are studied.

Lethbridge is located in southwestern Alberta where agriculture is perhaps the most diverse of anywhere in Canada, combining both dryland and irrigated crops. The prairie city is in the Dark Brown soil zone, near the boundary where Dark Brown soil meets Brown. It is in the Arid Grasslands (Mixed Grass Prairie) ecoregion, and spear, wheat and blue grama grasses dominate in the native state.

Lethbridge has a climate of extremes. Short, warm summers are followed by long, cold winters. But the climate is not as extreme as in the Brown soil zone farther east. Warm Chinook winds from the west bring some respite from winter, although these winds can be hard on overwintering plants and can cause drought-like conditions in the summer. Lethbridge is in the Chinook area of the Dark Brown soil zone; farther north in this soil zone there is less Chinook influence and the climate is slightly cooler and moister.

The Dark Brown soil zone at Lethbridge receives about 387 mm of precipitation annually, and has a growing season of 100 to 120 days without frost (refer to Table 2).

Irrigation for a dry land

Irrigated farming makes up an important part of the agricultural industry in Alberta. About 12 per cent of the province's agricultural production comes from irrigated land, even though only four per cent of arable land (1.1 million acres or 450,000 hectares) is irrigated.

Irrigated farming is very different from dryland farming. Not only are large amounts of water applied to the land, but the quantities of other inputs like fertilizers are also much greater than those used in dryland farming. Irrigation is therefore most economical where the climate is driest, as crop yields are most improved by irrigation in dry soils. Economic returns from irrigation diminish as the climate becomes progressively moister.

Irrigation in Alberta is most economical in the Chinook region of the Dark Brown soil zone and in the Brown soil zone, represented by the Lethbridge and Bow Island study sites, where the main limitation to agriculture is the lack of sufficient moisture. There is no heat limitation, so special crops do quite well when irrigated — often better than they would farther north where the growing season is shorter and cooler. As a result, these areas produce the most diverse, high-yielding and valuable agricultural crops on the Prairies, despite their dry climates.

Soft white spring wheat, alfalfa and barley are the main irrigated crops. Soft white spring wheat yields higher than hard red spring wheat, normally a dryland crop. The soft wheat is lower in protein and gluten than the hard wheat, and makes excellent cookie and pastry flour. Alfalfa is valuable because of an expanding livestock industry. Irrigated barley is also sold as feed grain and silage to support this industry.

Sugar beets, another irrigated crop, are more valuable than cereal crops. Sugar beets are grown at Taber, Bow Island and Vauxhall in the Brown soil zone, and at Coaldale in the Dark Brown soil zone. Other crops grown with irrigation include sunflowers,

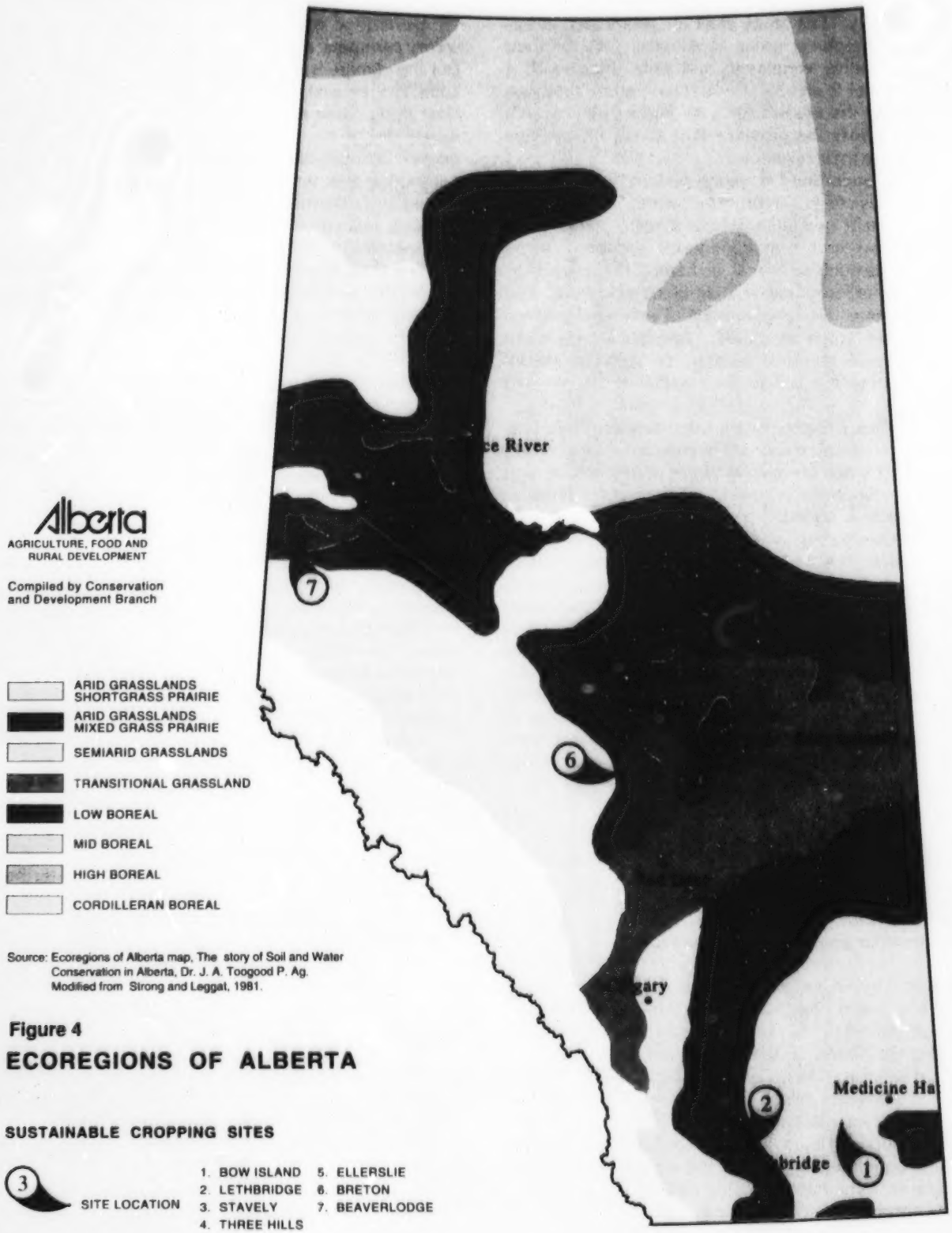


Figure 4

ECOREGIONS OF ALBERTA

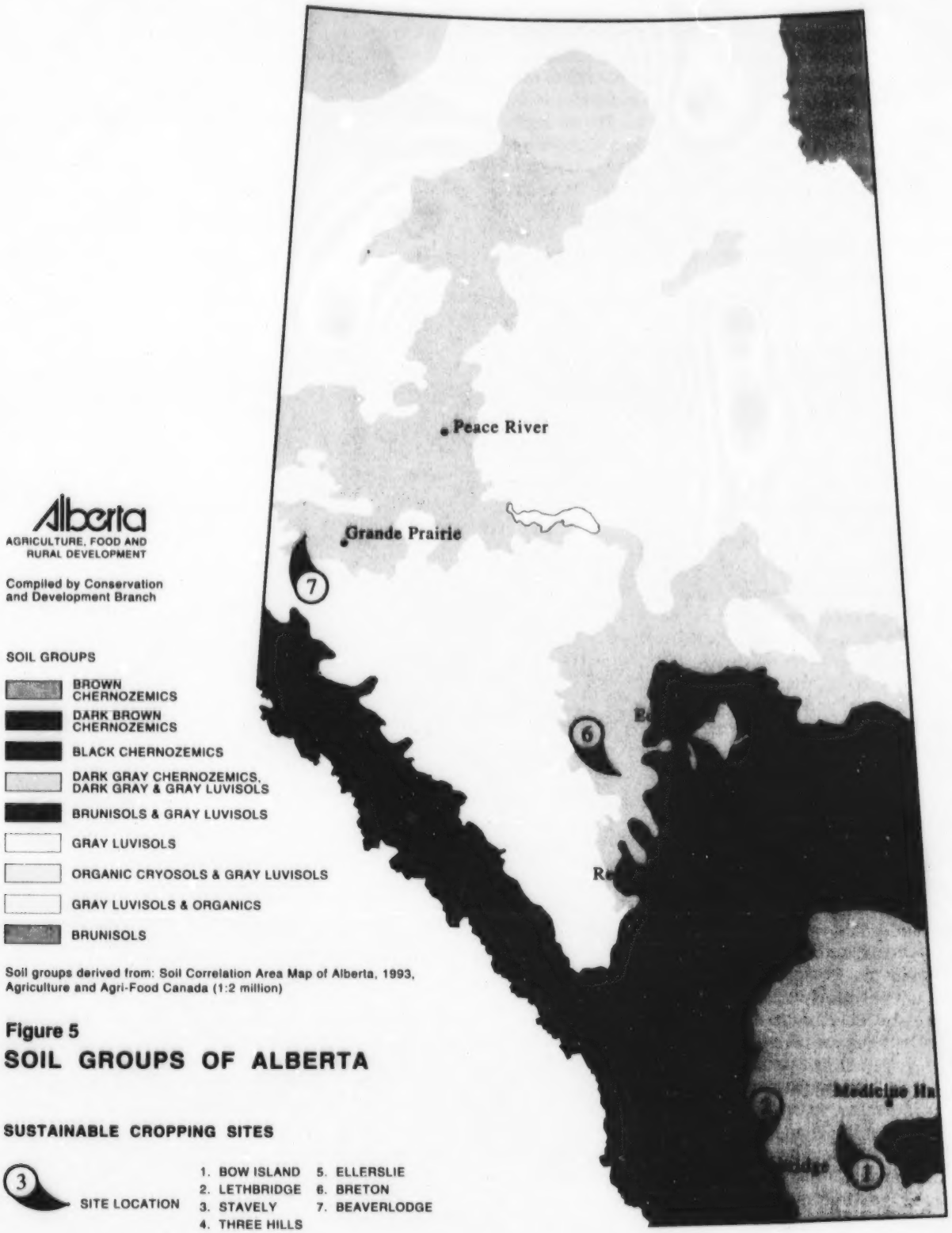


Figure 5

SOIL GROUPS OF ALBERTA

beans, peas, grain corn and potatoes. Canola, normally a dryland crop, can also be irrigated. Many irrigated crops such as beans, peas and alfalfa also fix nitrogen and improve the fertility of the soil.

In southern Alberta, cereal crops, alfalfa and sugar beets have been grown with irrigation for many years, and advances have been made. For example, there were once many acres of irrigated hard red spring wheat, but now soft white spring wheat is known to be more suited to irrigation.

Long-term studies on native rangeland

A substation of the Lethbridge Research Centre is nestled in the foothills west of Stavely, about 80 kilometres northwest of Lethbridge. It is the site of another long-term study — not on the sustainability of cultivated agriculture, but on the sustainability of a native grassland ecosystem for grazing use by cattle.

Grassland ecosystems are important in Alberta. Almost one third of the Northern Great Plains in Alberta is still native rangeland — the highest proportion of the Prairie provinces — which amounts to about 6.5 million hectares (16 million acres). There are also 1.4 million hectares (3.4 million acres) of Alberta rangeland that have been reseeded with introduced grasses.

The Stavely site is a unique and beautiful ecosystem in the Porcupine Hills. It features massive slopes dotted with wildflowers, trees and shrubs in depressions and on north-facing slopes, and views of a white-peaked mountain range stretching to the west. The site is in the Semiarid Grasslands (Fescue Prairie) ecoregion. The vegetation is dominated by fescue grass and oatgrass, and the soil is Thin Black. The surface Ah horizon is slightly thinner and more variable than in Thick Black soils, but the soil is still fertile and high in organic matter.

The foothills ecosystem is at the mercy of changeable weather patterns. There can be fierce indigo clouds one moment and scorching sunshine the next. The Stavely site has a cooler, moister climate than Lethbridge, with about 90 frost-free days and about 594 mm of precipitation annually. This is partly because of the higher elevation and the proximity to the Rocky Mountains. Temperatures and amounts of precipitation vary widely over short distances because of changes in elevation.

The land at Stavely has been greatly modified by human settlement within the last 140 years. Fires, once an integral part of the Fescue Prairie ecosystem, are now controlled. And the bison that once frequented the range for winter grazing have disappeared. These changes, combined with the cool, moist climate, have allowed some trees and shrubs to invade the Fescue Prairie.

The land is more suited to grazing than cultivation. Cultivation is not sustainable here. Severe erosion would occur on the steep slopes, and plant production would not be maintained. In contrast, since native ranges evolved to maintain the productivity of native grasses under the influence of grazing by bison, well-managed rangelands can sustain grazing by livestock.

LETHBRIDGE

Rotation ABC

When dryland Rotation ABC was established in 1910, the goal was to find the best way to grow wheat. Because of the dry climate in southern Alberta, it was recognized that farmers could not grow wheat continuously without the risk of crop failure during droughty years. Some combination of wheat and summerfallow was seen as the solution. Leaving a field fallow for a season, by not planting a crop and by controlling any weeds that grew, conserved moisture for the next year's crop. The question was, how frequently should farmers summerfallow? Rotation ABC was designed to answer this by testing different rotations of wheat and summerfallow.

On Rotation A, *Wheat*, there is no summerfallowing. Instead, wheat is planted every year on a single plot. Rotation B tests a *Fallow-Wheat* system, where land is summerfallowed once every two years. Rotation B consists of two plots, which each alternate between fallow and wheat. Rotation C tests a *Fallow-Wheat-Wheat* system, where land is summerfallowed once every three years. Rotation C consists of three plots, which each rotate between the three phases of the rotation. A series of other rotations using crops such as turnips, corn, alfalfa and peas were also established, but these were discontinued after several decades.

No fertilizer was added to Rotation ABC until 1967, when a 45 kg/ha treatment of nitrogen was included in the experiment. In 1972, 20 kg/ha of phosphate was added, alone and in combination with nitrogen, resulting in the present design of four fertilizer treatments: nitrogen, phosphorus, nitrogen plus phosphorus, and unfertilized.

Agricultural implements have changed since Rotation ABC began, and the changes have been incorporated into its management. Tillage imple-

ments have evolved to minimize soil disturbance and maximize the preservation of crop residues on the soil surface. The moldboard plow used in the early years was replaced by disc implements in the 1920s, which in turn were replaced by the wide blade cultivator in 1939. The introduction of herbicides in the 1950s and 1960s permitted a further reduction in the intensity and frequency of tillage. In addition to tillage implements, modern harvesting implements return crop residues to the field. Crop residues were removed from the plots before the combine harvester was introduced in 1943, after which residues were left on the plots.

B. H. Ellert

Wheat *(centre) grown continuously since 1910, on Rotation ABC at Lethbridge. To the left is the first year of wheat in the* Fallow-Wheat-Wheat *rotation, and to the right is the fallow phase of the* Fallow-Wheat *rotation.*

Suitability of design

Rotation ABC has several important features. It was established immediately after the sod was broken by settlers, so it provides information about the losses in soil organic matter that have occurred since cultivation began. It has a clear objective: to determine whether spring wheat can be grown on a grassland soil indefinitely without depleting the soil or harming the environment. It uses only three pertinent cropping systems to test this. Although the experiment is not replicated or randomized in accordance with modern statistical practices, the simplicity of its design makes it relatively easy and inexpensive to maintain. And its six large-sized plots, each covering an area of 0.6 hectares, reduce the effects that different landscapes might have on the results.

Rotation 116

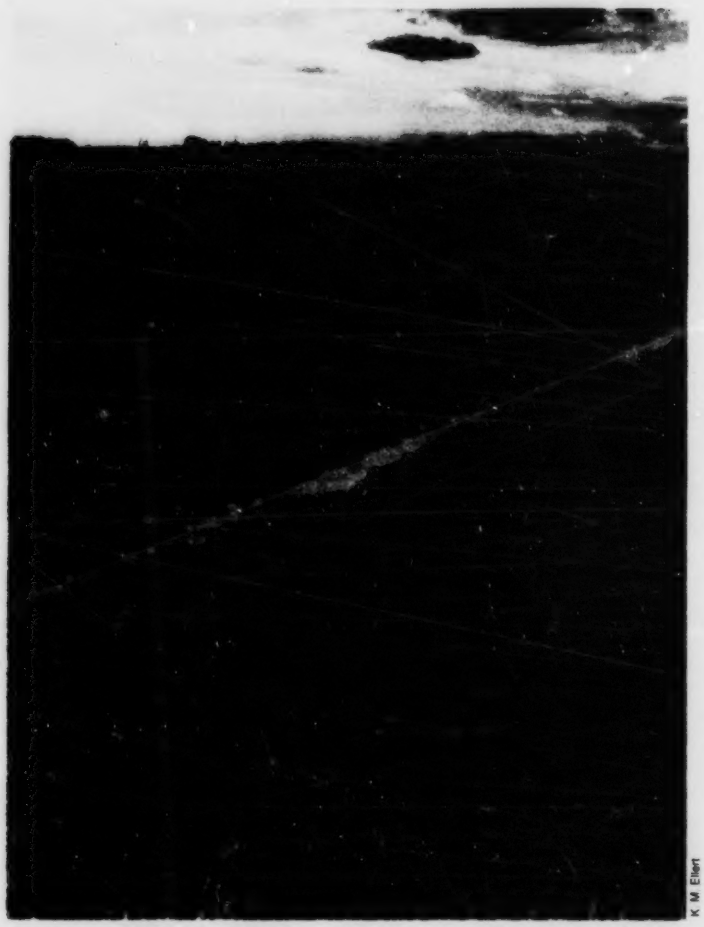
Dryland Rotation 116 was established in 1951 with the goal of diversifying the cropping systems used in long-term Rotation ABC. Forage crops such as alfalfa and Crested Wheat Grass were included. Winter wheat and barley, now discontinued, were also included in the original design. Manure was applied to some plots. In 1985, the experiment was modified to include annual legumes, native grasses, and fertilizer treatments.

Unlike Rotation ABC, Rotation 116 was established on land that had previously grown crops. The experiment consists of 116 plots, each 3.2m x 36.6m in size, much smaller than the plots of Rotation ABC. An important distinction from Rotation ABC is that the 13 cropping systems of Rotation 116 are each replicated four times. For example, the *Fallow-Wheat-Wheat-Hay-Hay-Hay* system has 24 plots, and the continuous *Wheat* system has four. Replication clarifies how the cropping systems influence results, by accounting for the random variability that occurs naturally in the plots.

In addition, each cropping system has a sequence of one or more 'phases,' which may be cropped or fallowed, and all phases of each system are represented every year. This accounts for year-to-year variability in weather and management practices, and also occurs in Rotation ABC.

Rotation 116 is probably the oldest replicated rotation experiment in western Canada. For more than forty years, the rotation has provided statistically valid results from a variety of cropping systems. But the small plot size limits the value of this rotation as a long-term study. There are 'edge effects,' where results are influenced by adjacent plots. Also, erosion and microclimatic effects within the plots influence the results more than in larger plots.

Rotation 116 also includes a flexible cropping system, two IF treatments which are only seeded if there is adequate moisture. Although farmers use



K. M. Ellert

Rotation 116 at Lethbridge, showing a native grass plot in the foreground and wheat rotations in the background.

flexible cropping systems, fixed treatments are often more useful to researchers. Results from fixed treatments are more easily analyzed, and can be used to advise farmers on the use of flexible systems.

Irrigated Rotation U

Irrigated Rotation U, believed to be the oldest continuous irrigated crop rotation in North America, was established in 1910, around the same time as dryland Rotation ABC.

Rotation U was originally designed as one 10-year rotation. In 1987 it was modified into three five-year rotations: (1) *Alfalfa-Alfalfa-Alfalfa-Wheat-Barley*, (2) *Fababeans-Wheat-Fababeans-Wheat-Barley*, and (3) *Corn-Wheat-Corn-Wheat-Barley*. Replicated nitrogen fertilizer treatments were also included in the modified experiment.

The alfalfa rotation is similar to the original rotation, testing the influence of growing irrigated alfalfa in rotation with annual crops. Fababeans, used in another rotation, are annual legumes that can fix large amounts of nitrogen. While this rotation is expected to benefit the soil, the corn rotation is expected to place the highest demand on soil resources.

Unlike Rotations ABC and 116, each phase of these rotations is not represented every year. It is argued that irrigation eliminates the effects of year-to-year variability in precipitation so it is unnecessary to include each crop every year, and land requirements would be too great.

K. M. Ellert

Irrigated Rotation U at Lethbridge, showing the rotation with corn growing next to recently seeded alfalfa. There is some volunteer barley in the alfalfa crop.

Other Long-Term Studies:
No-Till and Summerfallow Plots

In 1967 a No-Till Study was set up north of the Lethbridge Research Centre to test zero-tillage cropping systems. Six plots have not been tilled since that time. Although the plots are not replicated, they are among the oldest zero-tillage plots in North America. The experiment has become a demonstration site, showing that zero tillage is a viable option for farmers. Crops can grow well, weeds can be controlled, and the surface of the soil does not harden.

A Summerfallow Study was established the same year to compare how methods of fallowing, using different tillage implements and herbicides, affect the growth of subsequent wheat crops. The fallow is managed in eight different ways. Three are conventional tillage systems, using one of three different tillage implements: the oneway disc, the heavy-duty cultivator with sweeps, or the wide-blade cultivator (listed from greatest to least soil mixing). Five are minimal or zero-tillage systems, using chemical herbicides alone or in combination with the blade. The chemical fallow and blade treatments conserve more organic matter and are less prone to erosion when compared with summerfallow treatments tilled with the oneway disc or the heavy-duty cultivator.

RESULTS

- ***Summerfallowing conserves moisture and increases crop yield***

Even during the early years of Rotation ABC, it was suspected that keeping one-third of the land in summerfallow each year was the best cropping system for the driest regions of the Prairies. Today, the *Fallow-Wheat-Wheat* system is still recommended in the Brown soil zone and portions of the Dark Brown soil zone as the most cost-effective cropping system for farmers to use. The continuous *Wheat* system is more environmentally sound because it conserves soil organic matter and reduces soil erosion, but there is a risk of crop failure due to moisture shortage in a dry year. Rotations with fallow reduce this risk because moisture is stored in the soil during the fallow year.

Wheat yields on Rotation ABC are strongly influenced by the phase of the rotation; yields are high after a fallow year and low after a wheat year (Figure 6). Yields are lower on continuous *Wheat* because soil moisture is often depleted by wheat grown the previous year, whereas wheat grown on fallow benefits from stored moisture. The five-year moving averages used in Figure 6 illustrate long-term trends

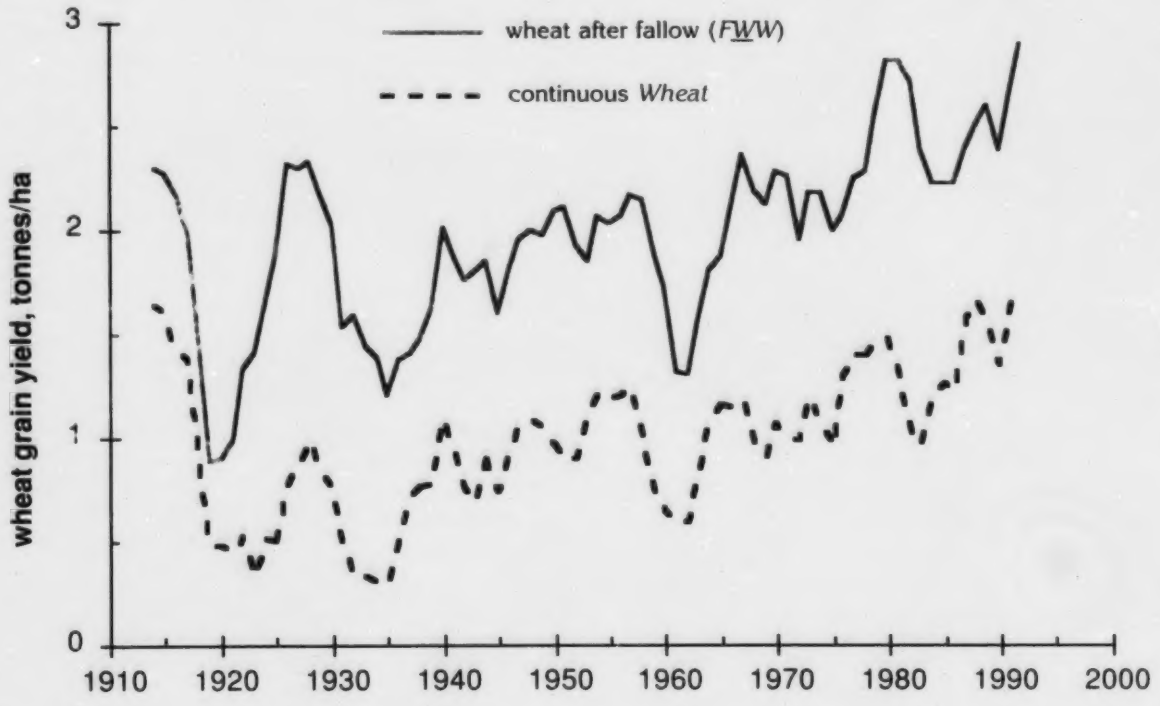


Figure 6. Wheat yields after a year of wheat are lower than after a year of fallow, on unfertilized Rotation ABC.

by smoothing out year-to-year fluctuations. For example, there is a slight upward trend in all yields, perhaps because of improved wheat varieties and management practices. Year-to-year variability conceals these trends in short-term experiments.

When wheat yields are averaged over the length of the rotation, they are remarkably similar among all three cropping systems in unfertilized plots. For example, in the unfertilized *Fallow-Wheat-Wheat* system, if the higher yield after a fallow year is averaged with the lower yield after a wheat year and the absence of yield during the fallow year, the yield of the rotation over the three years (or 'averaged rotation yield') is then comparable to the lower annual yield of the unfertilized continuous *Wheat* system (Figure 7). However, input costs are lower in cropping systems that include fallow. The fallow year requires some expenditures for weed control, but it does not require expensive inputs of seeds and fertilizers or the use of seeding and harvesting machinery.

- ***Adding fertilizers increases crop yield and soil organic matter***

While averaged rotation yields for *Fallow-Wheat-Wheat* and continuous *Wheat* are similar in unfertilized plots, adding fertilizers changes the story in Rotation ABC (Figure 7). When nitrogen and phosphorus fertilizers are added, yields of continuous *Wheat* are higher than the averaged rotation yields of *Fallow-Wheat-Wheat*. The fertilized continuous *Wheat* system is 18 and 28% more productive than the fertilized *Fallow-Wheat-Wheat* and *Fallow-Wheat* systems. This response to fertilizers in the continuous *Wheat* system, despite the lack of water storage found in fallow systems, suggests that nutrients, rather than water, are the biggest constraints to long-term production. Continuous cropping systems tend to produce higher yields per unit of available water than systems that include fallow. But only when nutrient constraints are removed, by applying fertilizers, is this more efficient use of water reflected in higher productivity.

In addition to increasing grain yields, fertilizers increase the amount of crop residues returned to the soil, especially under continuous cropping. These increased residues significantly affect the quantity of organic matter in the soil. Adding nitrogen fertilizer to the continuous *Wheat* plot has increased the quantity of soil organic matter by about 15%. Adding phosphorus fertilizer to this plot has increased the concentration of phosphorus in the soil by about 21%.

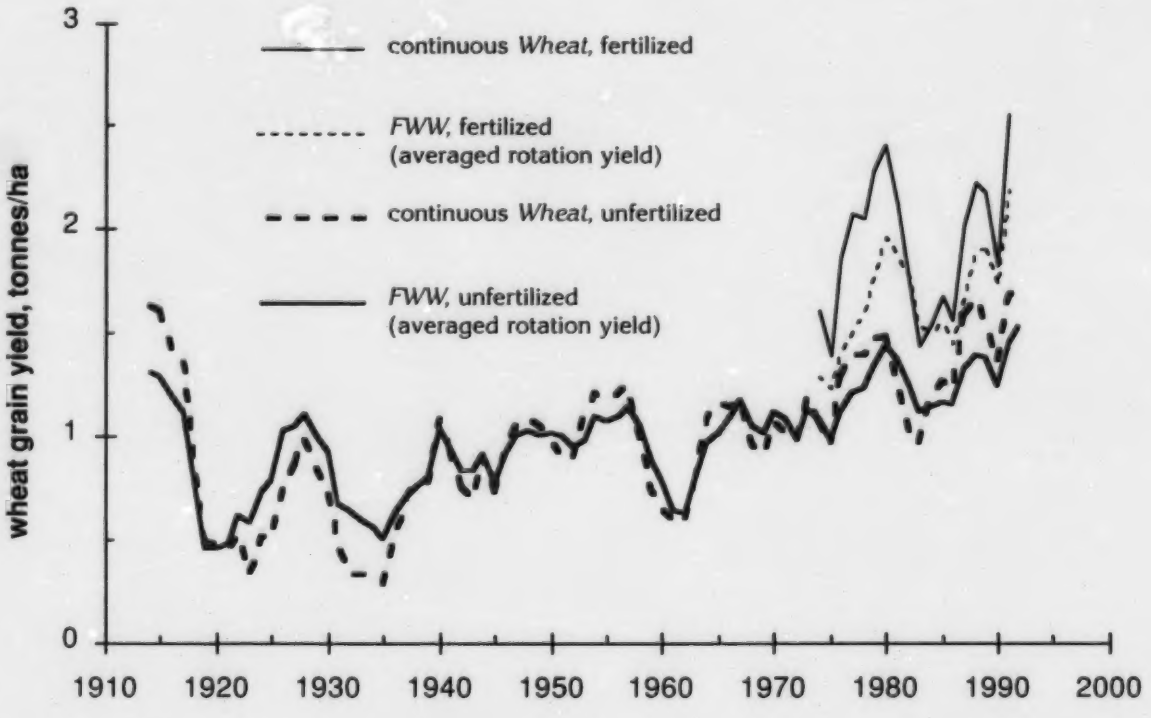


Figure 7. Wheat yields on unfertilized Rotation ABC are similar when averaged over the length of the rotation, and increase when nitrogen and phosphorus fertilizers are added.

- ***Initial declines in soil organic matter have levelled off***

Researchers in 1910 had the foresight to collect soil samples on Rotation ABC. This has allowed long-term changes in soil quality to be monitored. Important factors in soil quality are the amount and composition of organic matter contained in the soil. The concentration of soil carbon is an excellent indicator of the amount of organic matter.

After the cultivation of Rotation ABC in 1910, initial losses of soil organic matter were about 20%, but organic matter in the three cropping systems appears to have stabilized since about 1920 (Figure 8). Any changes since then have been minor, and it is unlikely that further substantial losses will occur, even within the next couple of centuries. The cropping systems appear to be sustainable, provided that erosion is successfully controlled.

The continuous *Wheat* system is the most environmentally sound of the three cropping systems. It retains the most organic matter, and therefore carbon, in the soil because organic matter decay is slowed by the dry conditions under continuous *Wheat*. Differences in soil carbon between the *Fallow-Wheat* and *Fallow-Wheat-Wheat* systems are minor.

- ***Soil organic matter is maintained by reducing summerfallow, adding manure and including forages in rotation***

The various cropping systems in Rotation 116 have had major influences on soil organic matter. The quantity of soil organic matter decreases with increasing frequency of summerfallow, so that soils under continuous *Wheat* contain the most, followed by those under *Fallow-Wheat-Wheat* and then *Fallow-Wheat*. Losses of soil organic matter in cropping systems with summerfallow are avoided either by adding livestock manure or including three years of perennial forages in the rotation.

Similar to the results observed in Rotation ABC, the various cropping systems in Rotation 116 influence the quality of soil organic matter as well as the quantity. The quality of soil organic matter can be determined by measuring the kinds of organic matter that decompose rapidly and release nitrogen for use by plants; the more of these kinds, the higher the quality.

Soil organic matter in cropping systems that include summerfallow is of poorer quality, because rapidly decomposable organic matter is lost during the warm, moist fallow year. Soil organic matter is of better quality under continuous *Wheat*, and in crop-

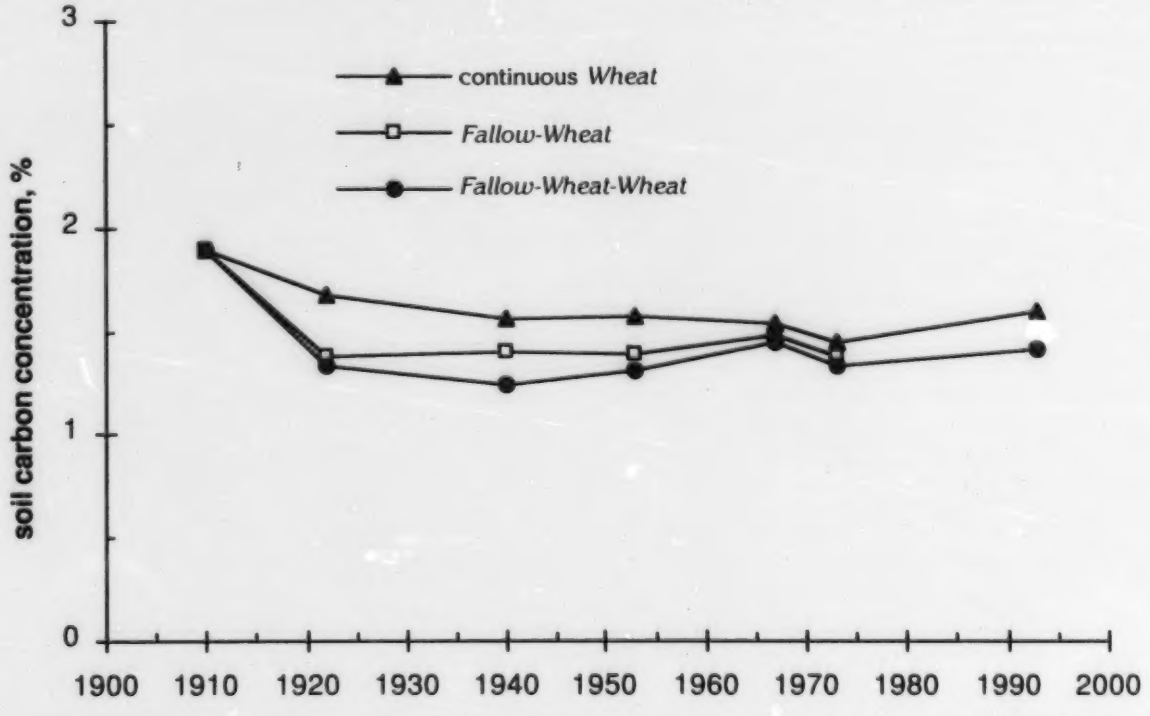


Figure 8. Soil carbon (0-15 cm depth) in a continuous *Wheat* cropping system and two fallow cropping systems, on unfertilized Rotation ABC. After an initial decline following cultivation, soil carbon levels have stabilized, with levels under continuous *Wheat* slightly higher than those under fallow systems.

ping systems that include manure or perennial forages. However, the greater amounts of rapidly decomposable organic matter are somewhat unstable, and may be lost if management is changed, for example if summerfallow is included in the cropping system.

- ***Irrigation can maintain productivity and increase soil organic matter***

Rotation U has demonstrated to farmers how to grow certain crops under irrigation. Data from the original 10-year rotation study showed that productivity can be maintained under irrigation. The original study also showed that alfalfa, usually an unsuccessful dryland crop in southern Alberta because of its high moisture requirements, can be successfully grown with irrigation. Alfalfa has become one of the most important irrigated crops in southern Alberta.

The quantity of soil organic matter in Rotation U has increased consistently over time. Irrigation increases organic matter by increasing the amounts of crop residues added to the soil. Whereas dryland cropping systems affect organic matter mostly in the surface soil layer (0-15 cm), in irrigated cropping systems increases in organic matter are most pronounced in the subsurface soil layer (15-30 cm), probably because crop residues and manure have been incorporated into that layer by plowing.

STAVELY

Rangeland Study

In 1949, a long-term study was set up at the Stavely Research Substation to compare how four different grazing intensities affected the condition of native range. Range condition is evaluated by the changes in plant species and soil characteristics that occur in response to grazing.

Like Rotations ABC and U at Lethbridge, the long-term study at Stavely was not replicated or randomized. Four fields with light, moderate, heavy, or very heavy grazing intensities were used. The corresponding stocking rates were 1.2, 1.6, 2.4, and 4.8 Animal Unit Months (AUM) per hectare. One Animal Unit is equivalent to one 454 - kilogram cow, with or without a calf, and AUM per hectare is the number of Animal Units on one hectare of rangeland, for one month.

RESULTS

- ***Changes in plant species***

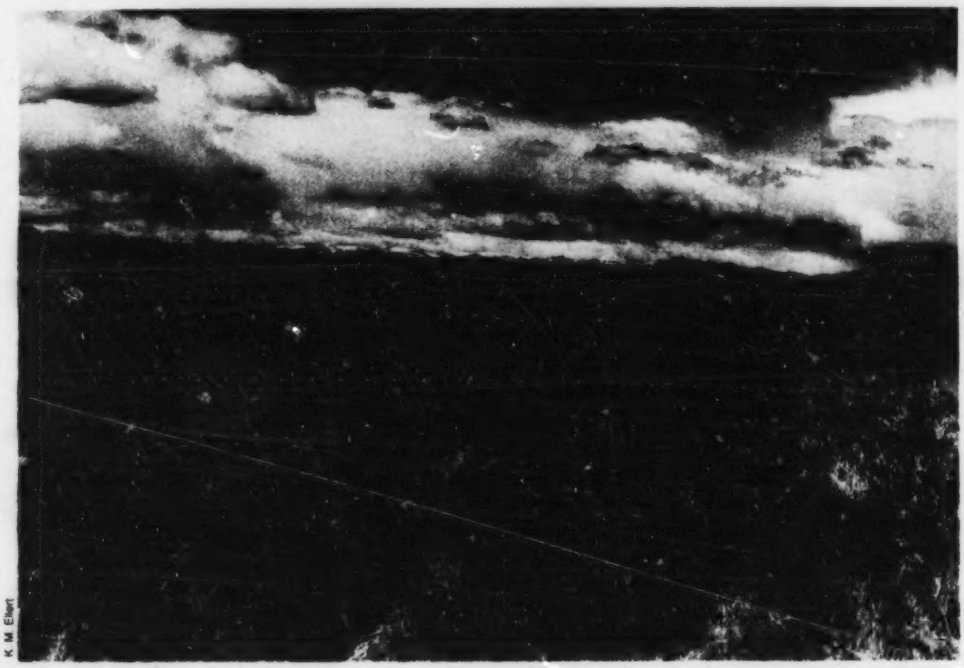
Rangeland deteriorates under heavy and very heavy grazing. Native grasses like Rough Fescue decline in numbers and are taken over by 'invaders' — introduced grasses like Couch Grass, Timothy and brome.

Many of the introduced grasses have different physiologies from native grasses. They produce more above-ground plant matter than below-ground root matter. Because their root systems are not well developed, they flourish only during years of adequate precipitation. Native grasses may have lower yields than introduced species but they produce stronger root systems, and are therefore more resilient during droughty years and more sustainable over the long-term.

Heavy grazing forces the grass plant to focus its energies on replenishing plant matter, thereby neglecting the root system.

- ***Changes in soil characteristics***

Soils are also affected by overgrazing. They



Ungrazed field (foreground) at the Stavely substation, showing excellent-condition fescue grassland with large tufts of Rough Fescue grass and some shrubs. The field in the background has been moderately grazed, and looks greener because there is less plant litter to mask the new spring growth.

become drier, warmer, and lighter in color, evolving into soils of a drier soil zone and less organic matter. At Stavely, they evolve from Black to Dark Brown soils if overgrazed.

The organic matter itself is affected. The Black soils at Stavely are formed under cool, humid conditions. The anaerobic microorganisms that thrive in this environment produce a complex type of organic matter, with large molecules that are resistant to wind and water erosion. Once the range is overgrazed, decades or centuries may be needed before the organic matter returns to its original state. In its place is organic matter that is less stable, and more erodible.

- ***Changes in range condition***

There was no change in the condition of the range after 32 years of light grazing. The moderate grazing intensity (1.6 AUM per hectare) is recommended for summer grazing of good-condition range in the area, despite a slight decline in Rough Fescue. A slight decline is deemed acceptable; some diversity is introduced into the ecosystem as other grasses increase. During the summer these other grasses are more palatable to cattle than fescue, which is preferred in the winter once it has matured. However, Rough Fescue was nearly eliminated at the heavy grazing intensity (2.4 AUM per hectare). The loss of Rough Fescue as a component of the Fescue Prairie ecosystem would mean the loss of opportunities for winter grazing, as well as the aesthetic loss of a natural ecosystem.

BRETON AND ELLERSLIE

North central Alberta
(University of Alberta)

The cropping system studies maintained by the University of Alberta include the second oldest crop rotation in Alberta, after the original Lethbridge crop rotations. The Classical Plots were established in 1930 at the Breton site, southwest of Edmonton near the town of Breton. Crop rotations are also studied at the Ellerslie site, established in 1980 near Edmonton.

The most fertile of prairie soils

The Ellerslie site, 10 km south of Edmonton, is still on grassland (Chernozemic) soils as are the Lethbridge and Stavely sites. It is in the Black soil zone, as is the Stavely site. But it is a Thick Black soil, rather than the Thin Black soil at Stavely. The surface layer is rich in organic matter, making it highly fertile. It is in the ecoregion referred to as Transitional Grassland (Aspen Parkland): the transition between prairie and forest. The vegetation consists of a mixture of grasses (such as fescue), shrubs, and bluffs of aspen trees.

A decline in fertility: the forest soils

The Breton site is 110 km southwest of Edmonton, near the town of Breton. Here we see a departure from grassland soils and an arrival to forest (Luvisolic) soils, specifically the Gray soils, which are less fertile than grassland soils. This is the low Boreal (deciduous and mixed wood) ecoregion, where the vegetation is dominated by aspen, with some White Spruce.

Differences in soils and vegetation occur because of differences in landscape and climate. Breton has a higher elevation than Ellerslie. It has a cooler, moister climate. Heat is the limitation to agriculture at both these northern sites, rather than the moisture limitation of the south. Breton has a severe to moderate heat limitation, and a growing season of about 80 frost-free days. Ellerslie has a slight to moderate heat limitation, and a growing season of 90 to 110 frost-free days. Breton receives about 547 mm of precipitation annually, compared to about 455 mm at Ellerslie.

The cool, moist climate at Breton has encouraged the growth of trees for thousands of years. And the presence of trees has likewise encouraged the development of Luvisolic, rather than Chernozemic, soils.

BRETON

Classical Plots

The Classical Plots were established in 1930 to find solutions to the problems of managing the nutrient-poor Gray soils. The plots were designed to compare two cropping systems, and to test soil amendments such as fertilizers, manure and lime. The original cropping systems were (1) continuous *Wheat* and (2) a four-year rotation with three years of cereal crops followed by one year of legumes. In 1938, the continuous *Wheat* system was converted to *Wheat-Fallow* so that weeds could be controlled. In 1939, the four-year rotation was expanded to five years of *Wheat-Oats-Barley-Forage-Forage.*

The forage crops of the five-year rotation have varied over the years, but have always included a legume. From 1939 to 1954, they were 'mixed legumes.' From 1955 to 1966, a mixture of alfalfa, red clover, brome, Creeping Red Fescue and Timothy was used. And in 1967, the mixture was reduced to alfalfa and brome, which was the recommended forage mixture for the area.

Several combinations of nitrogen, phosphorus, potassium and sulphur fertilizers were added to the plots. Farmyard manure was added every five years, and lime was added periodically. Several plots have never received fertilizers or manure, and are used for comparison.

Straw has always been removed when the cereal

R. C. Izaurralde

South-facing aerial view of the Breton Plots. An access road stems off the main road and divides the plot area. Shown from north to south are: native forest vegetation, the six 'series' of the Classical Plots (north of the access road), and, south of the access road from east to west, the Hendrigan, Zero Tillage and NSERC Plots. The grayish color of fallowed soils in the Classical Plots (fifth series from the left) is characteristic of cultivated Gray Luvisols and reflects low contents of soil organic matter.

crops are harvested, as was the practice in 1930. Tillage methods have changed over the years, and herbicides have been used since about 1964.

Major changes were introduced to the Classical Plots in 1980. Fertilizer treatments were revised to meet the recommendations of the day. The rates of nitrogen, phosphorus and potassium were increased.

The revisions to the Classical Plots came about because of a renewed interest in crop rotations, sparked by a debate about whether substance-based systems, dependent on high inputs like chemicals and fertilizers, could be replaced with knowledge-based systems.

Substance-based systems are designed to make farming simpler. Manufacturers incorporate their knowledge into chemicals and fertilizers, which are sold to the farmer who applies them. But there may be different effects depending on soil, climate and other factors. Knowledge-based systems are more complex. They integrate ideas. Knowledge comes from the farmer, who responds to each situation differently. There is

J. A. Robertson

The Hendrigan Plots at Breton showing mature barley in the foreground, grown continuously on that plot since 1980. Fababeans in the background right are part of the eight-year rotation.

some evidence that knowledge-based systems are more self-sustaining than substance-based systems, and therefore are important to the future of agriculture.

The renewed interest in crop rotations also resulted in two new crop rotations being set up at the Breton site by the University of Alberta, named the Hendrigan Plots and the Zero Tillage Plots. The Zero Tillage Plots were duplicated at the Ellerslie site.

Hendrigan Plots

The Hendrigan Plots were named for Lou Hendrigan, a local farmer who believed the best agricultural system for the Gray soils was a continuous forage system, grown to feed cattle on a mixed farm. He thought the best forage for the area was a mixture of fescue grass, which is suited to the soil and climate, and a legume such as White Dutch Clover. The purpose of the clover is to fix nitrogen from the atmosphere and supply it to the soil, and the grass adds organic matter, especially because of its large root systems.

The Hendrigan Plots, established in 1980, consist of three cropping systems: (1) continuous *Barley*, with straw returned to the plots after harvest, (2) continuous *Forage* (fescue grass and white clover, in keeping with Mr. Hendrigan's theories), and (3) an eight-year 'Agroecological' rotation of *Barley-Fababeans-Barley-Fababeans-Barley-Forage-Forage-Forage*, where the forage crop is a mixture of brome grass and red clover. The question of which was the better grass — fescue or brome — was a friendly debate between Mr. Hendrigan and the soil scientists at the University of Alberta.

Nitrogen, phosphorus, potassium and sulphur fertilizers are used in the cropping systems, but no nitrogen fertilizer is added to the Agroecological system because the clover and fababeans supply nitrogen. Some manure is added to the first year of barley in this system.

The ecology of the Agroecological rotation

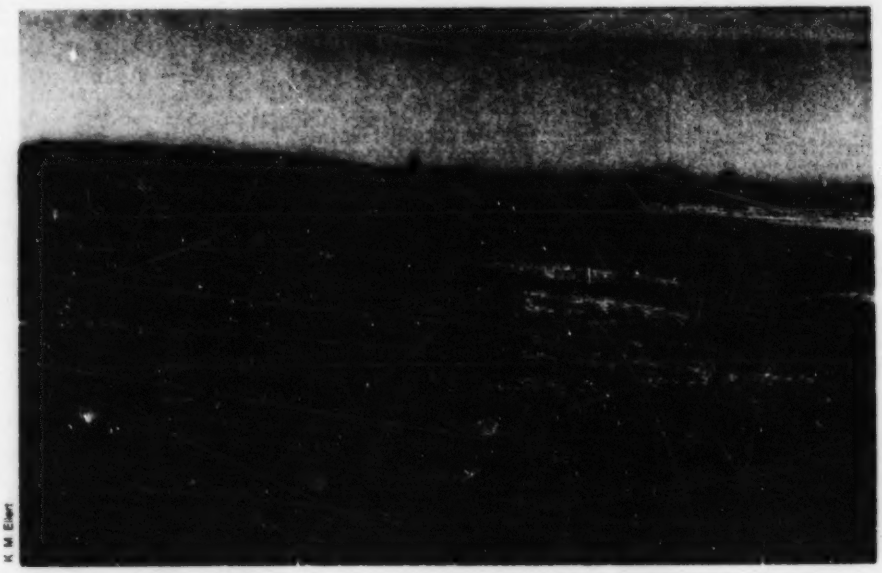
The Agroecological rotation incorporates the principles of ecology into an agricultural cropping system in several ways. There is minimal disturbance to the soil, so organic matter remains intact. Inputs of fertilizers and pesticides are infrequent. Nitrogen fertilizer is unnecessary because legumes replenish soil nitrogen during the three forage years of the rotation. Weeds are controlled by including crops with different rooting habits and life cycles in the rotation. This keeps soil microbial communities diverse and healthy, builds up soil organic matter, and improves soil structure and quality in the Gray soils.

Using different crops also makes efficient use of water, solar radiation and other resources. For example, the alfalfa grown during forage years starts earlier in the season than barley, and takes advantage of the resources available then. This increased 'resource use efficiency' improves productivity and yield, and there are few losses of nutrients and organic matter since the soil is seldom disturbed, especially in forage years. As a result, minimum input systems such as this can still produce high outputs. The Agroecological cropping system may help determine if minimum-input systems are sustainable.

Classical and Hendrigan plots compared

The Classical and Hendrigan plots showcase a broad spectrum of cropping systems. On one end of the spectrum, the *Wheat-Fallow* system of the Classical Plots is the most exploitive and conventional of agricultural systems, especially in north central Alberta. It is unnecessary to conserve moisture by summerfallowing in this region, but in the Classical Plots this system is used to control weeds.

On the other end of the spectrum, the cropping system most in tune with ecological principles is the continuous *Forage* (grass and legume) system of the



K. M. Ellert

The Zero Tillage Plots at Ellerslie, showing Black soil on tilled plots, and crop residues on untilled plots. The plots have been cropped continuously to cereals since 1980.

Hendrigan Plots. Because forages maintain themselves, it is a closed system in which the soil remains mostly undisturbed.

Next along the spectrum from 'ecological' to conventional agriculture is the eight-year Agroecological system (Hendrigan), then the five-year system of cereals and forages (Classical), then the continuous *Barley* system (Hendrigan), and finally the *Wheat-Fallow* system (Classical). The wide range of cropping systems allows researchers to observe changes in the soil that result from different agricultural practices.

ELLERSLIE (and Breton)

Zero Tillage Plots

The Zero Tillage Plots, established at Breton and Ellerslie in 1980, test (1) two tillage systems (conventional tillage and zero tillage), (2) two crop residue systems (removing straw and returning straw after harvest), and (3) two fertilizer treatments (no fertilizer and an application of nitrogen fertilizer).

The effect of using zero or conventional tillage is secondary to the effect of inherent differences between the Breton and Ellerslie sites (Table 4). The fertile Ellerslie soils produce higher grain yields and retain higher percentages of soil carbon than the less fertile soils at Breton. The differences between the soils at each site are related to corresponding differences in climate and vegetation.

Adding nitrogen fertilizer and returning straw to the soil after harvest are important management practices for improving grain yield and storing carbon in the soil (Table 5). Yields are higher with nitrogen fertilizer than without it. When straw is left on the field after harvest, the percentage of carbon in the soil is greater than when it is removed.

NSERC Plots

The NSERC Plots were established at Breton and Ellerslie in 1989, and were named for the agency that initially funded them (Natural Sciences and Engineering Research Council). There are three cropping systems: (1) continuous *Barley*, (2) a four-year rotation of *Fababeans-Barley-Barley+Peas-Barley*, and (3) continuous perennial *Grass* (Creeping Red Fescue). In the four-year rotation barley is 'intercropped,' or grown together, with field peas during the same rotation year. The legume supplies nitrogen to the barley, especially important the following year.

There are three nitrogen treatments, which vary

Table 4. The Zero-Tillage study: Comparisons of barley yields and soil carbon at different sites. The fields received nitrogen fertilizer (56 kg N/ha), and straw was returned to the soil after harvest.

Site	Tillage System	Grain Yield (tonnes/ha)	Soil C (%)
Breton	Zero Tillage	2.1	1.8
	Conventional Tillage	2.4	1.6
Ellerslie	Zero Tillage	3.2	5.6
	Conventional Tillage	3.8	5.8

Table 5. The Zero-Tillage study: Comparisons of barley yields and soil carbon using different fertilizer and straw management regimes, under conventional tillage at Ellerslie.

Fertilizer	Straw Management	Grain Yield (tonnes/ha)	Soil C (%)
Without N fertilizer	Straw Removed	2.4	5.3
	Straw Returned	2.2	5.7
With fertilizer (56 kg N/ha)	Straw Removed	3.6	5.3
	Straw Returned	3.8	5.8

with each rotation. The four-year rotation does not receive nitrogen, as it is added by the nitrogen-fixing legumes. In the continuous *Barley* system, nitrogen fertilizer is added to some plots and compared with other unfertilized plots. In the continuous *Grass* system, a fixed rate of nitrogen fertilizer is applied.

Unfertilized continuous *Barley* is limited by a lack of nitrogen, shown by its low nitrogen uptake (Table 6). While adding fertilizer to barley improves both grain yield and plant nitrogen, improvements can also be made using a legume in rotation with barley. By growing fababeans or field peas before growing barley, the soil is enriched with nitrogen, and grain yield and plant nitrogen uptake increase without the addition of fertilizers. This is an example of how low input systems can give high yields, as high input systems can, but without the expenses and soil disturbances characteristic of high input systems.

Two tillage systems, custom-designed for each site, are also tested. At Breton, conventional tillage and deep tillage are compared. Deep tillage enriches the surface horizon with clay from lower horizons. At Ellerslie, conventional tillage and zero tillage are compared.

Deep tillage and zero tillage result in higher grain yields and plant nitrogen uptake than conventional tillage (Table 7). Deep tillage brings clay and nutrients from lower layers closer to the soil surface, and creates a better root environment. The fababean crop flourishes, producing more nitrogen for the following barley crop, and the barley also grows better because of the improved rooting conditions. Zero tillage was also beneficial in this study, in contrast with results from the Zero-Tillage study which showed no real differences between zero tillage and conventional tillage.

RESULTS

- ***Summerfallowing is unnecessary in the Black and Gray soils***

Only about 10 to 15 per cent of the land in north central Alberta is summerfallowed, compared with 30 to 40 per cent in the Lethbridge area. But the per-

Table 6. The NSERC study: How different sources of nitrogen affect barley yields and plant nitrogen, under zero tillage at Ellerslie.

Cropping System	Nitrogen Source	Grain Yield (tonnes/ha)	Plant N (kg/ha)
Continuous *Barley*, control	Soil	2.6	58
Continuous *Barley*, fertilized	Soil, Fertilizer	3.2	86
Fababeans-Barley†-Barley+Peas-Barley	Soil, Fababeans	2.9	77
Fababeans-Barley-Barley+Peas-Barley†	Soil, Peas	2.8	77

† Data is obtained for the underlined barley crop in rotation sequence

Table 7. The NSERC study: How different tillage systems affect barley yields and plant nitrogen, in *Fababeans-Barley†-Barley+Peas-Barley* cropping systems at Breton and Ellerslie.

Site	Tillage System	Grain Yield (tonnes/ha)	Plant N (kg/ha)
Breton	Conventional	1.5	37
Breton	Deep	1.8	43
Ellerslie	Conventional	2.2	54
Ellerslie	Zero	2.9	77

† Data is obtained for the underlined barley crop in rotation sequence

centage in the north may still be too high as there is ample moisture for most crops, and weeds can be controlled with herbicides.

On the Gray soils near Breton, the practice of summerfallowing is especially destructive because organic matter is lost from soils that are already low in organic matter. Conservation tillage and good cropping systems have much potential to increase amounts of organic matter in Gray soils, as improvements make a big difference in soils which are naturally low in organic matter.

The Thick Black soils near Ellerslie contain large amounts of organic matter. Decomposition of organic matter due to summerfallowing may be slower because these soils are more resilient, but erosion of soil and organic matter will occur, especially if summerfallowing continues. This can already be observed in lighter-colored crests of hills in fallowed fields, which indicate that soils have eroded and organic matter has been lost.

- ***Using longer crop rotations that include forages increases crop yield and soil organic matter***

Cultivated Gray soils are low in organic matter, which leads to poor structure, or tilth. Hard crusts form on the soil surface after rainfalls. Adding organic matter is the best way to improve soil tilth. This is done by using long crop rotations that include forages such as perennial grasses and legumes, often mixed together, in addition to annual crops like cereals. The legumes fix nitrogen that would otherwise have to be added as fertilizer. Increased yields from this nitrogen means more organic matter is added to the soil. The grasses also contribute organic matter in the form of roots from their large root systems. The north-central portions of Alberta are well-suited to rotations that include perennial legumes because moisture is adequate, unlike southern portions of the province.

In the Breton Classical Plots, the advantages of the five-year rotation compared with the two-year rotation are shown in higher grain yields of wheat (Figure 9). Also, barley yields in the Agroecological cropping system of the Hendrigan Plots have been shown to exceed those in the continuous *Barley* cropping system 38 per cent of the time. Legumes can be used as the sole source of nitrogen for barley production on Gray soils, without sacrificing grain yield or soil quality.

The percentage of organic carbon in the soil, and therefore the quantity of soil organic matter, is also

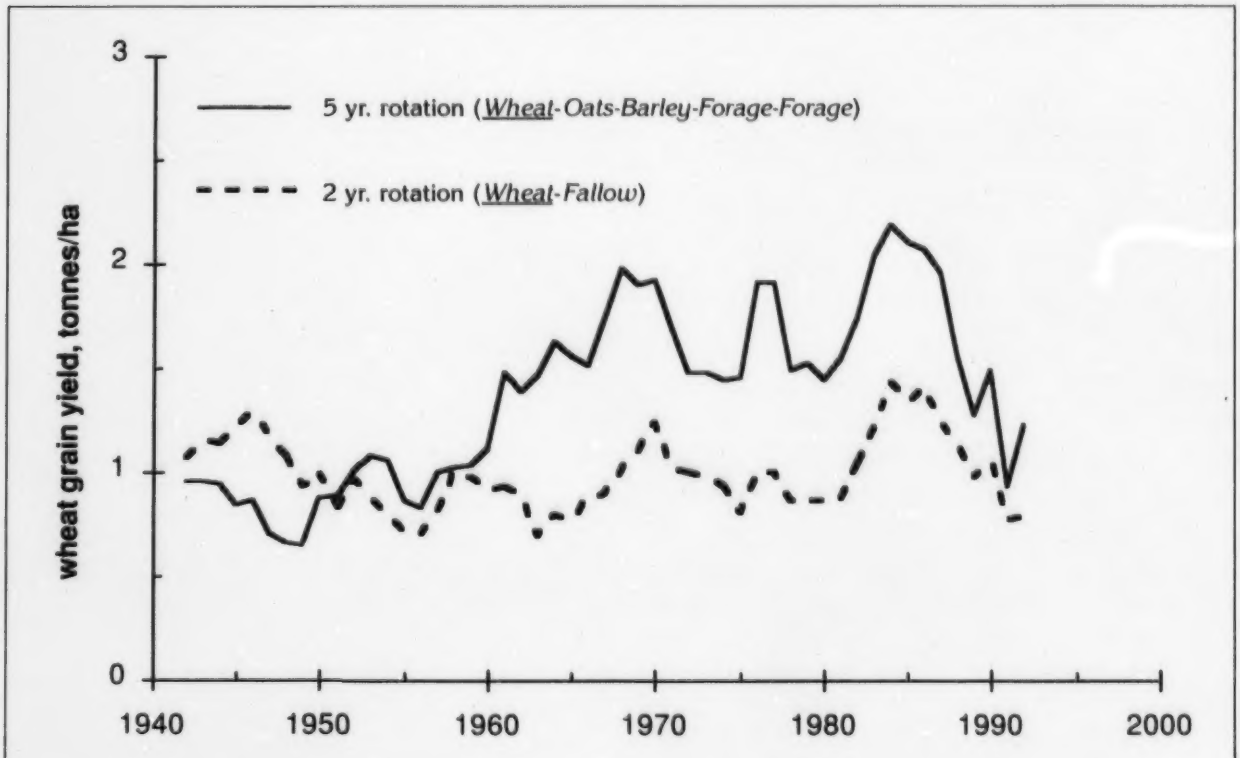


Figure 9. Wheat yields generally are higher in the five-year rotation than in the two-year rotation of unfertilized Classical Plots at Breton.

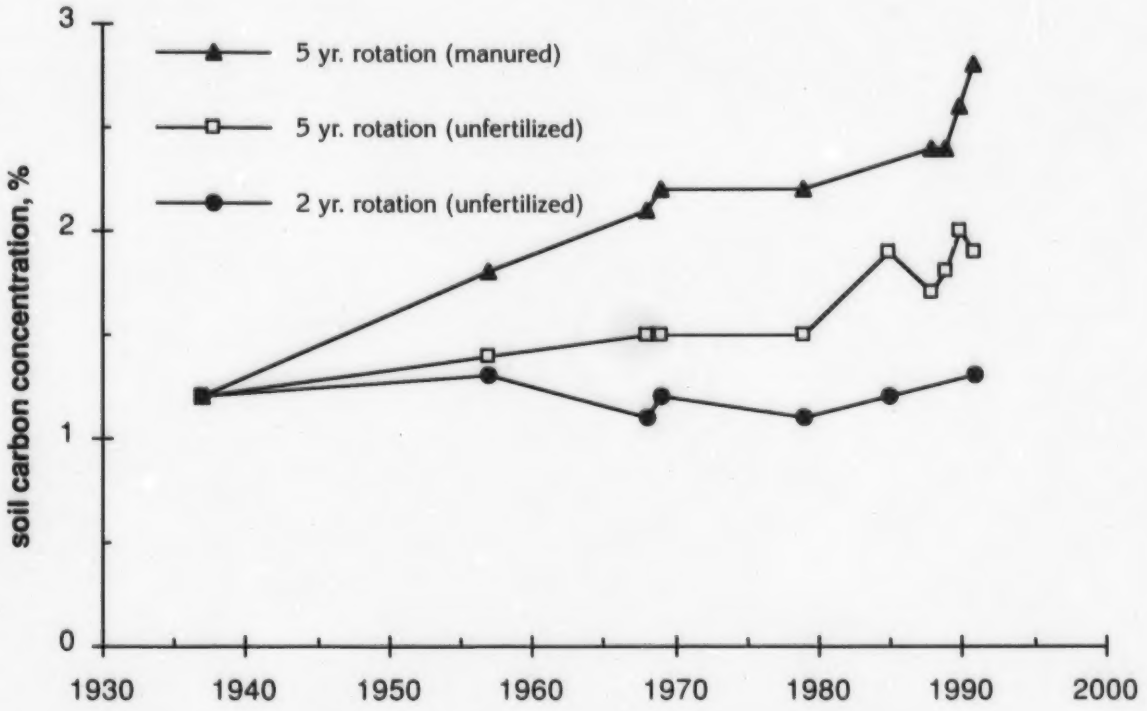


Figure 10. Soil carbon (0-15 cm depth) in unfertilized two- and five-year rotations of the Breton Classical Plots, and the effect of manure in the five-year rotation. There is more soil carbon in the five-year rotation, especially when manure is added.

higher in the five-year than the two-year rotation of the Breton Classical Plots, when unfertilized plots are compared (Figure 10).

Although Black soils are naturally higher in organic matter and have better tilth than Gray soils, they also benefit from cropping systems with forages. Long rotations with forages break cycles of weeds, diseases and insects that can invade short rotations with annual crops. Perennial forages also provide continuous cover that resists erosion, compared to annual crops that are tilled.

- ***Adding fertilizers and manure increases crop yield and soil organic matter***

Cultivated Gray soils are deficient in nutrients because the soils are low in organic matter, and they have developed in a moist region where many nutrients have been washed away. The soils are most deficient in nitrogen, but sulphur, phosphorus and potassium may also be limiting.

When either fertilizer or manure is added to the two-year rotation of the Breton Classical Plots, wheat grain yields are greatly increased relative to the control plots (Figure 11). Nitrogen fertilizer increases the amount of organic matter in the soil, and phosphorus fertilizer increases the concentration of phosphorus in the soil.

The fact that the manured treatment in Figure 11 is not only comparable to the fertilized treatment but sometimes surpasses it, suggests that farm enterprises can successfully integrate cereal, forage and livestock production. Forages are grown to feed livestock, manure is applied to the land to provide nitrogen for the cereal crops, and the forage crops sustain themselves because they include a nitrogen-fixing legume. Nutrients are recycled from forage, to feedlot, and back to the land in the form of manure.

Adding manure also has a large effect on the percentage of soil carbon in the five-year rotation of the Breton Classical Plots (Figure 10). With amounts of soil organic matter in unfertilized plots already higher in the five-year rotation than in the two-year rotation, adding manure made the quantity of soil organic matter in the five-year rotation even higher.

Even in Black soils, which are naturally high in organic matter, nitrogen is often deficient when the soils have been farmed intensively for decades. Most of the nitrogen is contained in inactive forms of organic matter, and is unavailable to plants. Only a small percentage of the soil organic matter (<25%) is

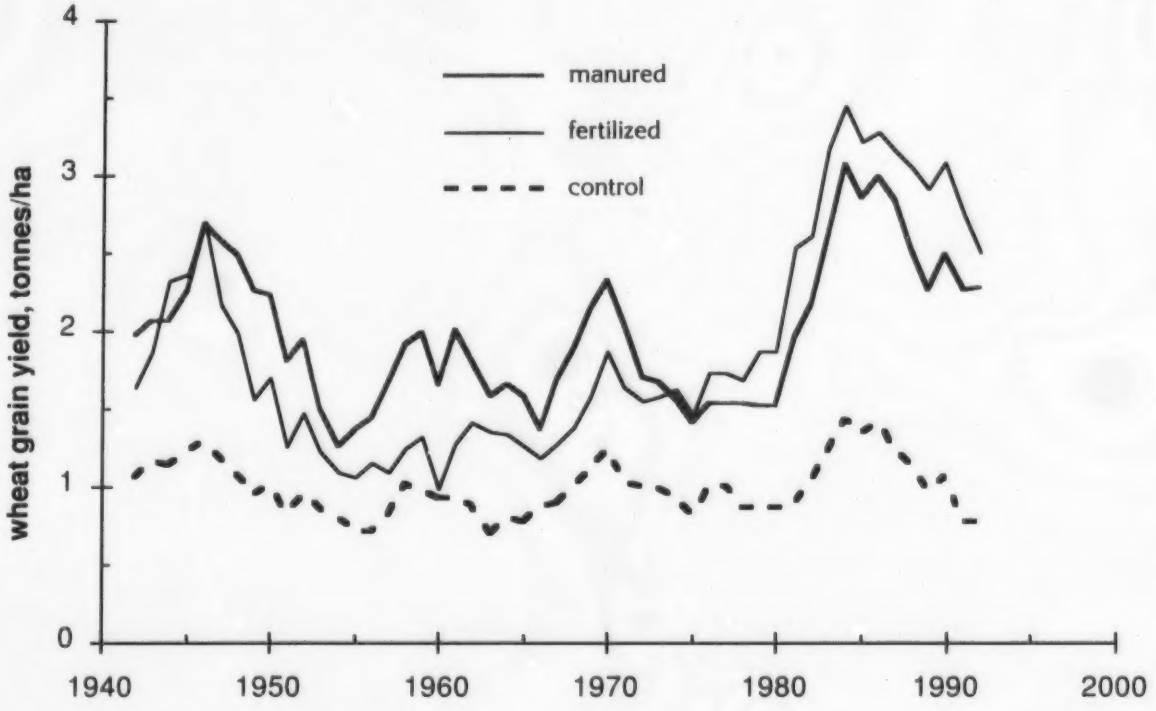


Figure 11. Wheat yields in the two-year rotation of the Breton Classical Plots are higher when either fertilizer or manure is added.

present in active forms that supply nitrogen and other nutrients to plants. Consequently, it is the active portion that is essential to plant growth. When active soil organic matter becomes depleted after decades of intensive cropping, nitrogen fertilizers must be added instead.

- ***Acidic soils can be improved by liming***

The application of lime can be beneficial on acidic soils in the northern parts of the province. Liming reduces soil acidity and supplies calcium and magnesium to plants. Legumes such as alfalfa and clover are especially sensitive to acidic conditions, and are most likely to benefit from liming.

Gray soils are especially prone to acidification because they are formed in a moist environment where the minerals that prevent acidity have been washed away by rain. Management practices such as zero-tillage and nitrogen fertilization may also contribute to soil acidity. Under zero-tillage, more nutrients may be washed through the soil because pores are large in undisturbed soil.

Black soils are less prone to acidification because they are drier, and they naturally contain more of the minerals, such as calcium and magnesium carbonates, that prevent acidity.

BEAVERLODGE

Northwestern Alberta
(Agriculture and Agri-Food Canada)

In 1968, crop rotation studies were established at Beaverlodge on Gray to Dark Gray (Luvisolic) soils. The land was mainly poplar forest before it was cleared in 1956. The site is in the low Boreal (deciduous and mixed wood) ecoregion, similar to the Breton site, and aspen and White Spruce dominate. The annual precipitation is about 468 mm, and there are about 105 frost-free days. The site has a moderate heat limitation to agriculture.

The Beaverlodge site has high summer temperatures and low precipitation for its latitude. It is warmer and drier than the Breton site, which is somewhat unexpected since it is farther north. As mentioned earlier, the Breton site receives about 547 mm of precipitation annually, and has only about 80 frost-free days. The heat limitation at Breton is also more severe than at Beaverlodge, where the potential for agriculture is improved by the long summer days of a more northern latitude.

Four cropping systems were established at Beaverlodge in the original study: continuous *Barley*, continuous *Grass* (brome), continuous *Alfalfa* or *Red Clover*, and a six-year rotation of *Barley-Barley-*

Barley-Forage-Forage-Forage (one barley treatment and one forage treatment are present every year). The forage used in the six-year rotation was a mixture of brome grass and either alfalfa or red clover. When forages were included in the cereal cropping systems, the soil structure improved, as did the quality of the organic matter. These were important improvements as the Gray and Dark Gray soils normally have poor structures and are low in organic matter.

Unfortunately, the site was found to be subject to spring flooding from snowmelt because it was located in a low-lying area. Protection by windbreaks also slowed the evaporation of meltwater. The soil was high in sodium, and was somewhat acidic. The 1968 study was discontinued after about 25 years.

In 1991 a new long-term study was set up at a different site near Beaverlodge, with the goal of evaluating the sustainability of various cropping systems using conservation tillage in the Beaverlodge area. Preliminary results from other areas suggest that zero tillage may have several benefits such as resisting erosion, lowering fuel costs and improving soil moisture conservation.

New goals for the new study at Beaverlodge (1991)

The crops in the Beaverlodge area have shifted away from barley and oats, which were grown by the early settlers and were studied in the 1968 rotations. Now more wheat is grown, as well as two crops that are currently good economic choices: canola and field peas.

Wheat must be seeded early in the season to optimize the short growing season. Canola adds diversity to cropping systems, but it should only be grown every fourth year to avoid diseases like Black Leg. Peas, which can be harvested green or as grain, improve soil fertility and tilth and are tolerant of slightly acidic soils. Grasses such as brome and Red Fescue are also commonly grown.

Cropping practices are changing, too. Summerfallowing has been largely abandoned, and continuous cropping and zero tillage are now common practices. Summerfallowing is not needed to conserve moisture in this area, and it is not recommended because it ruins the structure of Gray soils. A *Wheat-Wheat-Fallow* rotation is included at the new Beaverlodge study site, but only for comparison with the other sites in the province.

Tillage practices, when used, are also changing. Periodic deep tillage is increasingly common, where clay is mixed from the B horizon into the nutrient-poor Ae horizon, improving its fertility. As a result, soils are improving and organic matter is increasing.

A new perspective on agriculture prevails. There are different markets and different ideas for cropping systems. The goal now is to increase productivity and preserve the environment at the same time, by moving towards continuous cropping and zero tillage in this area.

The Beaverlodge Rotation

The new study site was established on a Dark Gray soil 0.5 km east of the town of Beaverlodge. Six cropping systems were set up: (1) continuous *Wheat*, (2) *Wheat-Wheat-Fallow*, (3) *Wheat-Wheat-Canola*, (4) *Wheat-Wheat-Peas*, (5) continuous *Grass* (brome) and (6) continuous *Forage* (Red Fescue). The systems each have two tillage treatments: conventional tillage and zero tillage.

During the 1968 study, brome grass was found to increase soil organic matter and have a rehabilitative effect on the land. But other grasses, like Red Fescue, have not been compared until now.

2. More Recent Studies

BOW ISLAND
Southeastern Alberta
(Alberta Agriculture, Food and Rural Development)

When a quarter section of land near Bow Island was purchased by the Alberta government in 1990 to compare varieties of special crops, a unique opportunity was presented to expand the network of the cropping systems study to include a site in the Brown soil zone. Before 1991, there were no dryland studies in this soil zone within southeastern Alberta.

The Bow Island site is in the Arid Grasslands (Shortgrass Prairie) ecoregion, and spear and grama grasses dominate. This is the driest region in Alberta. It receives only about 358 mm of precipitation annually. It also receives the most sunshine and heat. There are 110 to 140 frost-free days.

Because of the extreme aridity of Alberta's Brown soil zone, irrigation is commonly used to increase productivity, with much success. But dryland farming is also widely practiced in this region. The most common dryland crops are wheat, barley and canola. Barley, although often grown farther north because it requires more moisture than wheat, actually produces a better grade that is suitable for malting when grown on dryland in the south.

The Bow Island Rotation

The Bow Island studies compare the sustainability of conventional cropping systems — continuous *Wheat*, *Wheat-Fallow* and *Wheat-Wheat-Fallow* — with the three more 'ecological' cropping systems described below.

The *Annual legume-Wheat* system: Most perennial legumes are unsuited to dryland farming in the Brown soil zone, because they use too much moisture. But newly developed annual legumes, many of which originate in Australia, are being adapted for the Prairies.

One such annual legume is the Chickling Vetch (*Lathyrus sativus*) used in the *Annual legume-Wheat* rotation at Bow Island. Annual legumes have less than a growing season to sap moisture from the soil because they are plowed under as green manure in early July. Questions about how well they reseed and grow in subsequent years, and how well they fix nitrogen are being studied. The experiments will determine the value of these legumes as alternatives to conventional summerfallowing within cropping systems in the Brown and Dark Brown soil zones.

The *Flax-Wheat-Fallow* system: As a way to introduce diversity into the *Wheat-Wheat-Fallow* system, one year of wheat is replaced with flax, a drought-tolerant oilseed. This can have multiple benefits. It can break up cycles of diseases and insects that plague wheat, such as the sawfly outbreaks that occurred until the 1960s when resistant varieties of wheat were developed. It can produce higher yields than on two consecutive years of wheat. And the roots of flax are often more successful than wheat roots at penetrating dense subsoils, or 'hardpan,' that can develop below the soil's surface.

The continuous *Grass* system: This is a low maintenance system, which most closely simulates the natural ecosystem. Weeds are controlled by maintaining a healthy stand of wheatgrass. Annual seeding is unnecessary. To remain productive, the grass system requires nitrogen fertilizer annually since plant matter is removed each year as hay, rather than being added back to the soil, and there is no legume in the system.

The effects of fertilizers are tested in each cropping system. The *Wheat* and *Wheat-Fallow* systems each receive five fertilizer treatments to determine the optimum rates of nitrogen and phosphorus, alone or in combination, and the effect of applying manure every six years. The other four systems each receive one fertilizer treatment. The *Wheat-Wheat-Fallow* and *Flax-Wheat-Fallow* systems receive a combination of nitrogen and phosphorus. The *Annual legume-Wheat* system receives only phosphorus because it produces its own nitrogen, and the *Grass* system receives phosphorus when established, and nitrogen every year after that.

K. M. Ellert

The Bow Island study site, showing flax and fallow of the Flax-Wheat-Fallow *system (foreground) and continuous* Wheat *(background). The Sweetgrass Hills in Montana can be seen faintly on the horizon.*

Each replicate of the cropping systems covers an area of 8m x 16m, which is divided between the fertilizer treatment and the unfertilized, or control, treatment. The rotations are managed as minimum tillage systems. Weeds are controlled with herbicides early in the season, followed by about two tillage operations later on.

Although it is too soon to detect differences in organic matter and soil quality, initial results show that the optimum rotations are ones that receive a balanced dose of nitrogen and phosphorus.

THREE HILLS

Central Alberta

(Alberta Agriculture, Food and Rural Development)

There was still a gap in the representation of geographical areas in Alberta. The Lethbridge site represented the Dark Brown soil zone in the south, but a Dark Brown site was needed farther north, outside the Chinook region. Also, a significant amount of arable Alberta land is transitional between the Dark

Brown and Black soil zones. Known as Thin Black soil, it has more organic matter than the Dark Brown soil found near Lethbridge, but less than the Thick Black soil found near the Ellerslie site.

The Three Hills long-term study site, located three km southeast of the town of Three Hills, was established in 1991. The site is technically on Thin Black soil, with Dark Brown soils nearby, and is outside the Chinook region.

In addition to a soil transition, the Semiarid Grassland vegetation at Three Hills is also transitional — between the Arid Grasslands (Mixed Grass Prairie) and the Transitional Grassland (Aspen Parkland). The annual precipitation at Three Hills is about 408 mm, and there are 90 to 110 frost-free days. The area is moister than Lethbridge and less susceptible to wind erosion, making it one of the areas in Alberta with the greatest potential for increased yields.

Because moisture is usually adequate, summerfallowing is not recommended in the Three Hills area. In fact, summerfallowing has decreased dramatically in this area since the early 1990s. Where summerfallowing is practiced, the number of tillage operations are often reduced from five times to three: in mid-June, mid-July and mid-August.

Another benefit of the adequate moisture is that farmers can use longer, more diversified cropping systems that include oilseeds, legumes and forages along with conventional cereal crops. In particular, more canola and field peas have been grown since the early 1990s.

The Three Hills Rotation

The Three Hills study consists of nine cropping systems: the conventional continuous *Wheat*, *Fallow-Wheat* and *Fallow-Wheat-Wheat* systems as well as 'ecological' cropping systems that include oilseeds, legumes, continuous forage crops, fall-planted crops and green manures. Five fertilizer treatments are compared in each cropping system to determine whether nitrogen alone, phosphorus alone, nitrogen combined with phosphorus, or manure is optimal. These four treatments are compared with an unfertilized treatment.

Perhaps the most 'ecological' system is the low input *Fall Rye-Wheat-Peas+Oats silage* system. Fall rye is seeded late in the growing season and is harvested early the following year. The next spring, wheat is seeded into the rye stubble. Peas and oats are seeded the next year, and are taken off early in the growing season as silage, after which fall rye is seeded again. The continuous cropping aspect, as well as the nitrogen added by the peas, benefit the soil. The use of herbicides only during the wheat phase reduces their impact on the environment. Fewer pests build up in this system. This system is based on the Agroecological rotation of the Hendrigan Plots at Breton. Another cropping system, *Wheat-Canola-Barley-Peas*, is not only beneficial to the soil but also economical because of the diversification of crops.

One possible cropping system to be included in the future might be three years of cereals or oilseeds followed by four years of forages, including a grass and a legume. Forage crops are good for the soil because the grass adds organic matter in the form of roots. Forages are also self-sustaining because the legume fixes nitrogen. Such a cropping system would likely be feasible in this region, which receives more rainfall than the Dark Brown soils to the south and east.

K. M. Ellert

Recently seeded research plots at the Three Hills study site. Two permanent forage plots can be seen midway and at the end of the plot.

IV. IMPLICATIONS FOR THE FUTURE

We naturally suppose, having grown up with this particular farming system, that it will go on and on, forever.

J.Stan Rowe
author
Home Place: Essays on Ecology
1990

The ultimate goal of long-term agricultural studies is to determine the sustainability of different cropping systems. There are three main aspects to sustainability. Will the cropping system sustain soil quality, and therefore crop productivity? How will the cropping system affect and sustain the rest of the environment — including water, wildlife and the atmosphere? And will the cropping system be economical? Will it sustain livelihoods and rural communities?

1. Agricultural Sustainability

Agricultural sustainability refers to the long-term production of crops and livestock. Farmers must be able to produce acceptable yields without impairing the future productivity of the land. To do this, the quality of the soil must be maintained. Organic matter must be conserved, as that is the major source of nutrients for crops; soil erosion must be prevented; and fertilizers and pesticides must be used with care to prevent pollution of soil, water and air.

PRINCIPLES OF AGRICULTURAL SUSTAINABILITY

Judicious use of inputs

A basic principle of agricultural sustainability is to replace what is removed, and to minimize pesticides and other inputs.

Nutrients are removed from the soil when harvested products are exported from the farm. Nutrients, especially nitrates, are also lost when they are washed from the soil into the groundwater or when they are released from the soil into the atmosphere. Whether exported or lost, nutrients must be added in accordance with crop needs.

When nutrients are supplied in excess amounts or at the wrong time, they are often lost. The efficient use of nutrients, epecially nitrogen, depends on applying the correct amount of fertilizer, and on synchronizing supply and demand. The supply of nutrients from soils and fertilizers should coincide with the demand for nutrients by plants. Nitrogen from crop residues and legume plowdown should also be taken into consideration. When losses of nutrients are minimized, fewer nutrients need to be replaced, and less fertilizer needs to be added.

Similarly, irrigation water can be used more efficiently if the water supply is scheduled to coincide with the crop's water use. This also helps prevent salinization and the washing away of nutrients, caused by over-irrigating.

Pest management should be integrated, so that several methods of control are used rather than relying solely on pesticides. Biological and mechanical control methods are alternatives. Pesticides that are used should be immobile. They should not persist in the environment, but instead should break down before getting into water supplies and food chains. Rotating crops also reduces the need for pesticides by preventing pest outbreaks.

In the 1950s, pesticides and fertilizers became widely available, and farmers soon became dependent on them to produce high yields. During the 1980s, the LISA concept (Low Input Sustainable Agriculture) was advocated because of rising input costs and concern about the environmental impact of high-input, intensive agriculture. The idea was that agricultural systems that used fewer inputs were more sustainable, both economically and environmentally.

The LISA concept was somewhat controversial, but its central idea has remained: we must develop sustainable agricultural systems that use fertilizers and pesticides judiciously, without becoming overly dependent on them.

Knowledge-based agricultural systems

Agricultural sustainability requires an intimate understanding of environmental constraints on crop production. The principle of knowledge-based systems is that knowledge can reduce the reliance on manufactured inputs such as fuel, fertilizers and pesticides. Each farming situation, with its unique challenges or problems, is considered individually. If farmers customize their cropping systems to fit their own particular climate and soil conditions, the cropping systems are more sustainable.

Knowledge-based systems recognize the value of knowledge and ingenuity gained from years of expe-

rience on the land. Information flows not only from commercial research labs and government institutions to the farm; increasingly, information is shared among farmers, individually and through farm organizations, and also flows from farmers to researchers.

Diversification

Agricultural sustainability is influenced by the diversity of crops grown, the diversity of the farm enterprise, and the diversity of the farm landscape.

Crop rotations have repeatedly demonstrated the benefits of crop diversity. Cycles of weeds, diseases and insects that can be encouraged by monocultures are broken. Moisture and nutrients are used more efficiently.

Wheat was once the main crop grown on the Prairies, so other crops were seen as 'special.' As more special crops were grown, they began to lose this status and are now more accepted. For example, ten years ago, 30,000 acres of peas were grown in Alberta, but today more than 300,000 acres are grown. Diversification has also been acheived by growing crops such as oilseeds (canola, mustard, flax, sunflowers), grasses, and legumes (annual pulse crops and perennial forages) in rotation with cereals like wheat and barley.

Diversification of the farm enterprise provides additional opportunities to optimize agricultural production. There is a growing recognition of the benefits of a mixed farm, where livestock is integrated with grain and forage production. Forages are grown to feed the livestock. Perennial forages protect the soil from erosion and improve soil fertility and structure, and legumes add nitrogen to the soil, reducing the need for nitrogen fertilizers. Manure is returned to the land, improving the cycling of nutrients and further reducing the need for fertilizers. If there are no livestock on the farm, alfalfa can be sold as a cash crop to pelleting plants, cubing plants or feedlots in Alberta. In addition to being ecologically stable and therefore sustainable, systems such as these are quite viable economically.

Agricultural sustainability may be enhanced by recognizing and working within the constraints of existing differences in landscape, or by encouraging greater landscape diversity. Hummocky terrain may be more suited to growing perennial forages than annual crops. Wetlands may not enhance agricultural productivity, but innovative management practices can allow wetlands and farming to coexist. Landscapes can be diversified by planting trees in shelterbelts, which prevents soil erosion and provides habitat for wildlife.

SUSTAINABILITY IN THE DRY SOIL ZONES: BROWN AND DARK BROWN SOILS

The need to conserve moisture in Brown and Dark Brown soils means that the most sustainable cropping systems are different from those suited to moister soils. While including perennial forages like alfalfa in cropping systems is an excellent method of improving the moister soils farther north, it is not recommended for dryland cropping systems in southern Alberta because the deep, perennial root systems use up too much water. Most of the alfalfa produced on Brown and Dark Brown soils is grown on irrigated land for this reason.

Summerfallowing to store soil moisture is often an accepted farming practice in the Brown soil zone and the drier parts of the Dark Brown soil zone. The frequency of fallowing usually varies from once in two years (*Wheat-Fallow* system) in the driest areas to once in three (*Wheat-Wheat-Fallow* system). By storing even an extra inch or two of moisture for next year's crop, wheat yields can be increased by five to 10 bushels per acre, which often makes the difference between covering input costs or falling short.

Where summerfallowing is necessary, the soil surface should remain covered with crop residues to prevent soil erosion and losses of soil moisture. Wide-blade cultivators and herbicides are useful to maintain residue coverage and prevent weeds from using up moisture.

Continuous cropping maintains soil organic matter and reduces soil erosion. But while beneficial to the soil, continuous cropping is not always economical in the dry soil zones. Although yields would be adequate in many years, crops might suffer from lack of moisture in certain years. Without crop insurance for drought, the yield might not pay for the seed, fertilizer and pesticide used to grow the crop. Annual reports from the Lethbridge Research Centre show about 15 crop failures on continuous *Wheat* systems since 1912, whereas there were only a couple of crop failures on the *Wheat-Fallow* system, assuming 10 bushels per acre or less is a failed crop.

SUSTAINABILITY IN THE MOIST SOIL ZONES: BLACK AND GRAY SOILS

Low input farming, which reduces productivity in the dry soil zones, works well in the moist soil zones of Alberta. The higher moisture levels provide more cropping options, including perennial forages and annual legumes, and eliminate the need for summerfallowing. Soils are conserved by reducing tillage, cropping continuously, and using longer rotations that include forages.

Since crop yields tend to be high on the Black soils relative to the drier Brown and Dark Brown soils, nitrogen requirements are also higher and fertilizer must be applied accordingly. Including a nitrogen-fixing legume in a cropping system means less fertilizer is needed. The Black soils are probably the most easily sustained soils in Alberta, provided erosion is prevented.

Sustaining productivity on the Gray (forest) soils

is more challenging, but the long-term plots at Breton have provided much information on appropriate management practices. Rather than relying solely on nitrogen fertilizers, which can lead to soil acidity, legumes can be used to sustain production. Where acidic soils occur, adding lime may be required to neutralize them. And adding manure not only provides another source of nitrogen, but also improves the structure of the soil and reduces the problem of crusts forming on the soil surface.

SUSTAINABILITY OF RANGELAND

The sustainability of agricultural production is an issue not only for cultivated agriculture, but also for rangeland. Grazing harvests plants, and nutrients are exported from rangeland systems through livestock production. But a greater proportion of plant growth occurs below the ground as roots, which are added back to the soil.

Rangeland in Alberta includes both native and introduced grasses. Native rangeland that is reseeded to introduced grasses is classified as improved range, but range ecologists debate whether introduced species are an improvement over the native grasses. Native grasses have larger root systems than introduced grasses, and are more sustainable during dry years.

Most agricultural systems exploit plant production. On native range, exploitation by grazing animals must be monitored and controlled to ensure that the grassland community is sustained.

2. Environmental Sustainability

Environmental sustainability refers to the long-term maintenance of a healthy environment. It encompasses more than agricultural production. Environmental sustainability is difficult to measure because it involves intangible qualities, such as clean air and water sources, habitat for wildlife, and the aesthetic beauty of the landscape.

The sustainability of agricultural production is closely tied to the sustainability of the environment. A healthy environment is essential to long-term crop production. Crop production, however, may have side effects that degrade the environment without necessarily impairing short-term production. For example, the cultivation of the native prairie and the drainage of wetlands have enhanced agricultural production while degrading wildlife habitat and ecosystem diversity. It is uncertain what effect this will have on the long-term production of crops.

A healthy environment is important to all people. The general public is becoming well-informed, and watches all industries, including agriculture, to prevent irreversible damage to the environment. Recent trends suggest that consumers are prepared to pay a premium for foods produced without degrading the environment.

Fortunately, many cropping systems that sustain long-term agricultural production also sustain the environment, and are economically sustainable. For example, a cropping system designed to synchronize nutrient supply with plant demand prevents groundwater and air pollution, and reduces the need for fertilizers.

3. Socio-Economic Sustainability

Economic and social sustainability refers to the financial aspects of the farm enterprise, and the viability of farm communities. In addition to earning income over the long-term, farmers are faced with the reality of maintaining a cash flow each year. As farms become larger to benefit from 'economies of scale,' rural areas become less populated. And when rural populations decline, communities wither and people must travel farther for services and recreation.

When economic conditions are tough, it may be necessary to reduce inputs like fertilizers and pesticides in order to cut costs. In some situations, investing in additional inputs is worth it, but in other situations it is not. For example, many crops show large responses to nitrogen fertilizer, but only if rainfall is adequate. Large investments can be risky, but the potential gain in yield might make the difference between a profit and a loss. Some long-term cropping system studies are investigating reduced-risk farming practices. The goal is to find out which rotations conserve soil, and at the same time make good economic sense.

Diversifying, or producing a variety of agricultural products, may help stabilize income by taking advantage of changing markets and economic trends. For example, when wheat prices are low, livestock prices may be higher, and income on a mixed farm will be more stable than on a farm that produces only one crop.

In addition to producing a wider range of agricultural products, farmers are diversifying into other business ventures. Many farmers now derive a portion of their income from sources off the farm, and from non-traditional farm enterprises. Farmers may work in urban centres part-time or during the winter. Diversified farm enterprises include guest ranches

and country vacation homes, guiding and outfitting, U-Pick fruit and vegetable farms, and fish ponds. Another trend shaping rural communities is the migration of urban dwellers to rural areas, made possible by modern communication technologies.

4. The Evolving Future of Long-term Cropping System Studies

Long-term cropping system studies will help researchers make recommendations to sustain the agricultural industry in the future. The long duration of these studies is what distinguishes them from other agricultural studies. Their role is seen more clearly by looking at them in the context of other studies (Figure 12).

MECHANISM STUDIES

These are research-intensive, or detailed, studies on how certain processes work. For example, the process of soil organic matter accumulation can be studied by measuring plant residue decomposition and soil respiration. Once these processes are understood for a particular soil and climate, researchers can suggest several cropping systems and management practices that potentially optimize these processes.

Although mechanism studies are highly intensive, they are low on the scale of space and time, which means they occur within a small area and are relatively short in duration.

FEASIBILITY STUDIES

These arise from the knowledge gained in mechanism studies. Several different cropping systems or management practices, suggested from mechanism studies, are tested to see if they are agronomically and economically feasible. In the example used, feasibility studies could identify the cropping systems most likely to conserve or accumulate soil organic matter.

Feasibility studies occur within a larger area and for a longer time than mechanism studies. Once a cropping system from these studies is recommended and becomes widely accepted, it may be justifiable to test it in a long-term sustainability study.

SUSTAINABILITY STUDIES

These long-term studies don't compare treatments so much as they look at the effect of time on a given cropping system. They test a recommended cropping system to determine if it is not only agronomically and economically feasible, but also good for the soil and the environment in the long-term. Results from sustainability studies should be applicable to a range of soil and climatic conditions. To ensure this, they should be conducted at a reasonably large scale, and at many different sites. This is why similar cropping systems are being compared at various sites in Alberta, as part of the Sustainable Cropping Systems Research Study. Although research intensity is relatively low, these studies must be maintained for a long-term data set to be used.

In the early rotation experiments, the purpose was to systematically test the feasibility of different cropping arrangements, and to share this information with farmers to help them decide which crops would grow best in their area and which management practices were most suitable. Some of these studies have been maintained to the present day, to become long-term sustainability studies.

Sustainability studies belong to society as a whole. The wealth of information collected from these experiments can help solve problems experienced by society in the production of food — be they agricultural, environmental or socio-economic problems — now and in the future. The researchers that maintain these long-term studies are their caretakers. They are custodians of the valuable information, and potential knowledge, these studies hold for members of society, for stewards of the land.

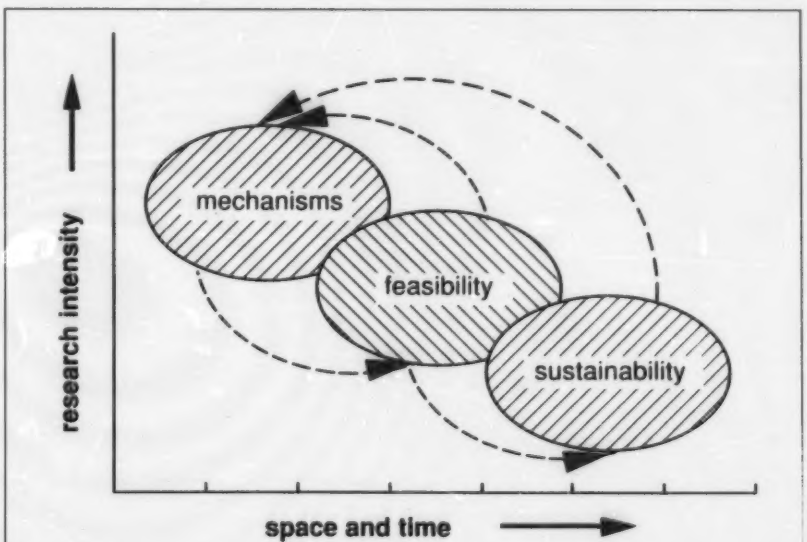


Figure 12. Long-term sustainability studies, in the context of other cropping system studies.

V. REFERENCES AND READING MATERIAL

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